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Work Practices Guide for Manual Lifting

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

WORK PRACTICES GUIDE FOR MANUAL LIFTING

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
Division of Biomedical and Behavioral Science
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ABSTRACT

Overexertion in the workplace accounts for a large number (and in some industries the majority) of disabling injuries. Most of these injuries involve the act of manually handling materials. This Guide summarizes a wealth of research and presents recommendations to control the various types of hazards associated with the unaided act of symmetric (two-handed) lifting of an object of known weight and size. Quantitative recommendations regarding the safe load weight, size, location and frequency of handling are presented. Factors which mitigate these recommendations are also discussed (e.g., worker training, physical fitness, strength, workplace layout, load handles, etc.). The Guide includes recommendations regarding both the selection and training of workers who must perform manual materials handling activities as well as presenting some engineering guidelines for the design of workplaces where manual materials handling is performed.

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FOREWORD

Overexertion injuries associated with manual materials handling (MMH) jobs (unaided lifting, lowering, etc.) continue to plague industry. The National Safety Council reports that at least 25 percent of all injuries, accounting annually for 12 million lost workdays and over 1 billion dollars in compensation costs, can be attributed to such mishaps.

Past attempts to deal with this complex problem have focused upon adopting rather arbitrary weight limits for lifting loads or using training procedures which emphasize "correct" lifting techniques; neither approach has had much effect upon reducing overexertion type injuries. This Work Practices Guide provides for a broader examination of the problem, encompassing medical, scientific and engineering viewpoints, and presents procedures to gauge the risk of overexertion hazards in MMH jobs and for risk control.

The first two chapters of the Guide identify the need for solutions to MMH problems based upon injury data and the extensive portion of the workforce engaged in such tasks. Chapter 2 further establishes this need through a review of epidemiological reports involving short and long term health effects associated with MMH tasks and identifies important job and personal risk factors.

Chapters 3,4 and 5 examine the problem in detail from the separate viewpoints of biomechanics, work physiology and psychophysics, respectively. Each approach develops criteria for establishing load limits in terms of load weight, horizontal location, lift distance and frequency of lift.

The next 2 chapters deal with hazard control procedures. Chapter 6 considers methods for avoiding worker-job mismatches by selecting workers for jobs based upon work capacity and physical attributes, and current knowledge of training procedures which might be employed to make workers aware of good lifting practices. Chapter 7 examines engineering control procedures and design criteria dealing with the workplace environment. Container and handle design, constraints imposed by the visual and thermal environment and materials handling system alternatives are considered here.

Chapter 8 incorporates the several approaches into a composite formulation for recommending load limits given different task factors. This material will be particularly useful to those directly charged with plant safety and health responsibilities.

Methods for identifying hazardous MMH tasks and evaluating these jobs in terms of excessive load weight, location and lift frequency are given in a readily understandable manner, along with recommendations for appropriate hazard control procedures.

The Guide does not address all MMH activities. Indeed, its primary focus is on lifting compact loads with both hands. For such work, it represents the current state of the art in risk control and presents a useful starting point to deal with complex problems presented by other manual materials handling tasks in industry.

ACKNOWLEDGEMENT

The recommendations contained in this 'Work Practices Guide for Manual Lifting' are based upon not only the results of investigations by scientists, engineers and physicians, but also on observations made at the jobsite by many individuals responsible for the development and implementation of programs in occupational safety and health.

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D. W. Badger and D. J. Habes coordinated the preparation of this document and had final editorial responsibility.

CHAPTER 1

JUSTIFICATION AND SCOPE

Overexertion in the workplace accounts for a large number (and in some industries the majority) of disabling injuries. Most of these injuries involve the act of manually handling materials. This Guide summarizes research on the hazards of manual materials handling in industry, and formulates recommendations to reduce the toll of human suffering and economic burden.

JUSTIFICATION AND RATIONALE FOR THIS GUIDE

For many years manual materials handling (MMH) has been recognized as a major hazard to industrial workers by authorities in the field of occupational health and safety. A particular concern has been shown for women and children performing such acts. In fact, during the period from 1930 to 1950 almost all the states enacted laws specifically limiting the weights that women and children could handle. All of these statutes have been subsequently struck down as unconstitutional since they discriminate against employment of all women without recognition of the large variation in capabilities between women.

As late as 1962 the International Labour Organization published an Information Sheet which stated limits shown in Table 1.1. These limits were primarily based on inspection of injury and illness statistics which depicted manual materials handling as contributing to about a threefold increase in spinal, knee and shoulder injuries, a tenfold increase in elbow injuries, and about a fivefold increase in hip injuries (ILO, 1962).

Table 1.1: ILO suggested limits for occasional weight lifting (kilograms) (ILO, 1962)

Age (years)	Men	Women
14 - 16	14.6	9.8
16 - 18	18.5	11.7
18 - 20	22.6	13.7
20 - 35	24.5	14.6
35 - 50	20.6	12.7
Over 50	15.6	9.8

Despite such guidelines, gross occupational injury and illness statistics continue to dramatize the problem in the United States and elsewhere. In 1973, the State of California reported 27% of all compensable injury and illnesses were due to overexertion (National Safety Council, 1975). Worker's compensation reports for Arkansas in 1976 show the same percentage (BLS, 1978). The later study also revealed, 1) an average of almost $3,000.00 per incident was spent in lost wage compensation and medical payments, and 2) 68% of the overexertion incidents involved lifting and 20% involved pushing and pulling objects. The State of Wisconsin reported the number of overexertion injury claims doubled between 1971 and 1977, as indicated in Table 1.2. The State of California reported over 68,000 overexertion injuries in 1973 alone (National Safety Council, 1975). Though the total for the United States in 1980 is not known, it will probably exceed 500,000 injuries.

Table 1.2: Wisconsin occupational injury and illness compensation records (Workmen's Compensation Division, 1978)

Year	Total Number of Overexertion Claims
1971	7,160
1973	9,875
1975	10,795
1977	14,411

Some industries have a greater overexertion injury rate than others. Table 1.3 depicts several high injury industry groups for Arkansas (BLS, 1978). A study of back strain and sprain injuries in Wisconsin in 1973 showed similar patterns between industry groups (Taugher, 1973). This latter study also reported that 61% of the back pain cases listed overexertion as the cause of the problem, and that about 7% of the back pain cases became permanently disabling to the individual. In this regard, a recent in-depth follow-up of 549 persons classified as partially but permanently disabled due to on-the-job injuries disclosed that less than one-third of the severe cases (particularly back problems) were able to return to work at any job, and that the worker's compensation payments replaced less than one-third of the wage earning capabilities of the workers (Grinnold, 1976).

If low-back pain cases alone are used as an indication of the economics involved, a recent report by the National Safety Council estimated over $1 billion dollars was spent on worker's compensation and medical payments in the U.S. in 1974 (Hirsch, 1977). Average awards in the railroad industry, which is not covered by the worker's compensation system are 10 times those awarded under the Worker's Compensation Act in some states (Hirsch, 1977).

Table 1.3: Arkansas 1976, Supplemental Data Systems Report (BLS, 1978)

Industry	% of All Injuries Reported as Overexertion	% of All Injuries Reported as Strain/Sprain
General Manufacturing of Durable Goods:	24%	29%
Household Furniture	35%	34%
Primary Metals	29%	34%
Fabricated Metal Products	35%	37%
Fabricated Structural Metals	38%	40%
Metalworking Machinery	43%	54%
Electric & Electronic Equip.	31%	38%
Ship Building & Repair	34%	40%
General Manufacturing of Non-Durable Goods:	30%	36%
Beverages	42%	40%
Knitting Mills	50%	60%
Chemicals & Allied Products	41%	54%
Inorganic Chemicals	45%	62%
Drugs	44%	38%
Rubber & Misc. Plastics	35%	45%
Tires and Inner Tubes	43%	55%
Wholesale Trade & Distribution:	32%	37%
General Merchandising Stores:	35%	38%
Service Industries:	36%	49%
Health Services	48%	62%

Clearly, human suffering and high economic burdens are greatest in industries which require manual handling of objects. Whether such acts are the primary cause or simply aggravate a pre-existing susceptibility to injury of the musculoskeletal system is often debated. Further, how many of the medical problems are falsely reported in the worker's compensation statistics is an open question. From a labor relations standpoint, the question is irrelevant. The fact is that the physical act of manual materials handling in industry is regarded as hazardous by many workers who claim, with regular success, that such caused harm and resulting disability. Be the harm of organic or psychological nature, the facts presented support the need to reduce the exposure to such acts as a matter of protecting worker health and well-being. Evidence of the epidemiological, biomechanical, physiological and psychophysical bases for such claims are presented in this guide to further define the exact conditions which seem to be of most concern to both scientists studying the problem and exposed workers.

EXPOSED POPULATION

A large and diverse group of industries appear to have significant overexertion injury and illness claims, as reported in Table 1.3. How many workers in these industries are actually exposed to hazardous manual materials handling is difficult to estimate. Assuming for the moment that lifting a 20 kilogram (44 pound) object once a day could be hazardous (see Table 1.1) for the occupational groups shown in Table 1.4, it is estimated that over 30 percent of the total workforce is exposed. If this mix of occupations were representative of the U.S. workforce then over 30 million workers are exposed daily. It should be noted that, with the exception of farm workers, all occupational groups listed in Table 1.4 are expected to increase in employment between 1970 and 1980 from 5% to 40% (Wisconsin Bureau of Research and Statistics, 1974).

Table 1.4: Estimated work force performing manual materials handling activities in Wisconsin (Wisconsin Bureau of Research and Statistics, 1974)

Craft Workers:	137,000 workers or 60% of total (especially carpenters, brick layers, plumbers, structural iron & steel, tin smiths, tool & die, mechanics, & telephone installers)
Operatives:	100,000 workers or 30% of total (especially press operators, packagers, sanders & buffers, welders, truck drivers, bus drivers, railroad brakemen & switchmen, delivery person)
Service Workers:	132,000 workers or 60% of total (especially janitors, waiters & waitresses, nurse assistants, porters, firefighters, police, housekeepers, groundskeepers)
Laborers, Except Farm:	65,000 workers or 90% of total (especially construction, freight handling, garbage collection, lumbering, stock handling)
Farm Owners & Laborers:	131,000 workers or 100% of total
Total Work Force in Wisconsin (1970):	1,703,810 workers
Estimated Workers Performing Manual Materials Handling:	565,000 or 32% of total

An added complexity in determining the exposed worker population stems from the continually changing mix of personal risk factors. As suggested by the ILO (Table 1.1) both gender and age of the work force modify risk. Figure 1.1 depicts the total employment by gender in the U.S. from 1966 through 1976. An analysis of such trends by the Women's Bureau of the U.S. Department of Labor (1975) stated:

> "The number of women employees increased at a much faster rate than men workers did. Women made up 39% of the total employment in 1974 compared to 34% in 1964. Most of the increase in women workers was in four major industry divisions that showed the fastest growth:
>
> Services: 2.8 million increase
> Government: 2.6 million increase
> Wholesale & Retail Trade: 2.2 million increase
> Manufacturing: 1.4 million increase"

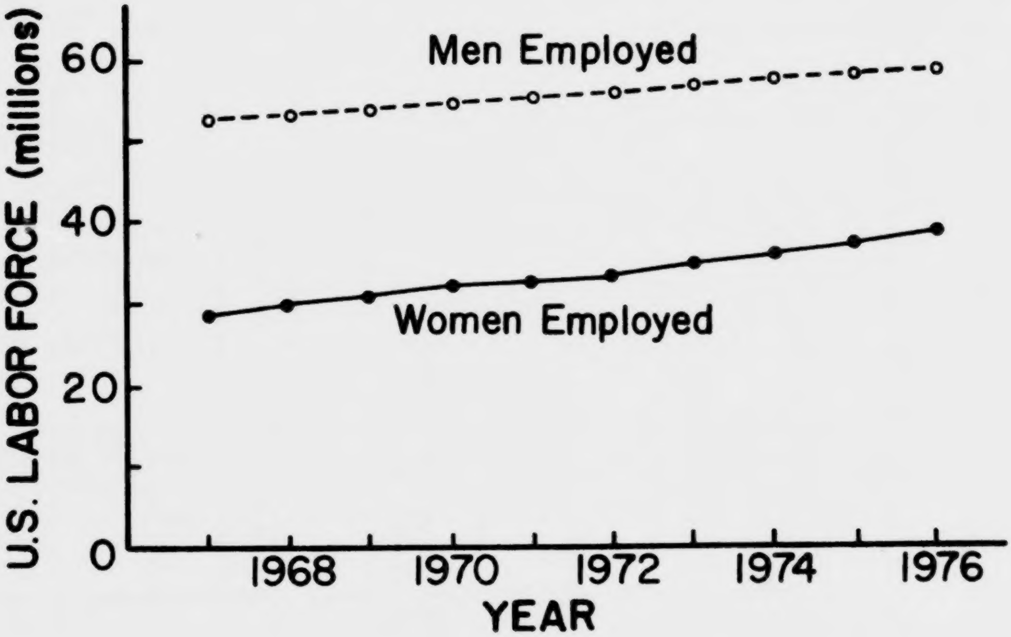


Figure 1.1: Employment in United States by Gender, 1966-1976. (DOL, 1977).

What is disturbing in this regard in the prevalance of manual materials handling occupations in these industries, thus exposing more women to overexertion hazards. As an example, 8 out of 10 employees in the health services industry in 1974 were women (Women's Bureau, 1975). As depicted earlier in Table 1.3, this industry reported the highest proportion of overexertion injuries (48%) and the higher proportion of strains and sprains (62%). Presumably a majority of these incidents are attributed to patient handling by nurses, nurses aides and therapists.

It is clear that the number of women exposed to manual materials handling is increasing. Further, the workforce is aging. Figure 1.2 depicts this trend for women in particular for the last 30 years. The most rapid expansion of the women labor force has been in the age group 45 to 54 (Women's Bureau, 1975). The emergence of these and other susceptible groups into workplaces which were designed years ago for "strong, healthy, young males" will undoubtedly exacerbate problems of overexertion injury in the U.S. A work practices guide is needed to allow future workplaces to be designed safer and more productive for a changing workforce.

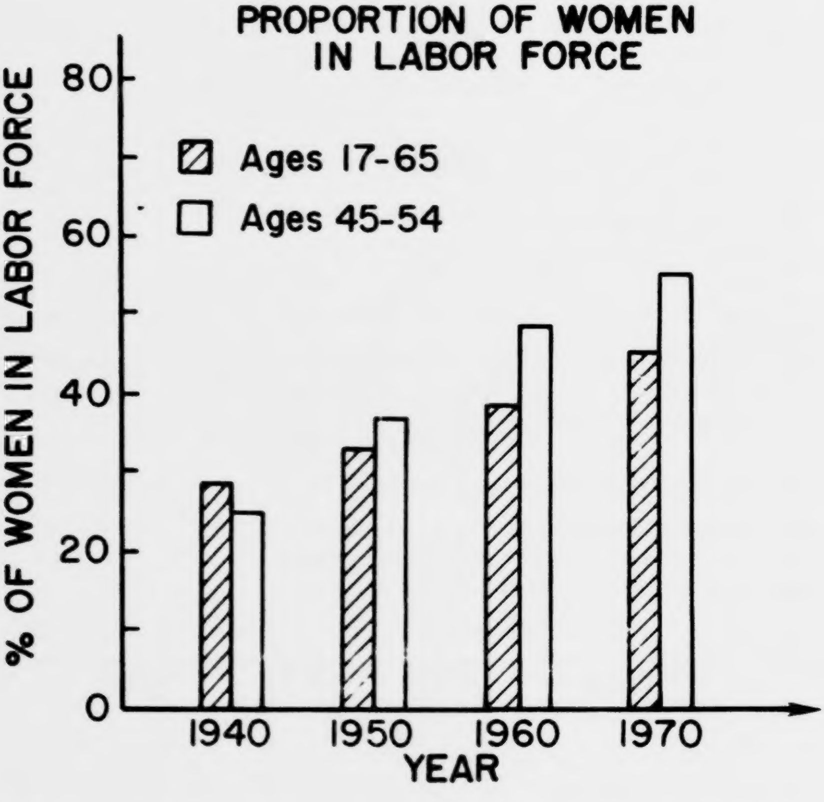


Figure 1.2: Female Labor Force as Percent of Women by Age (Women's Bureau, 1975)

SCOPE OF GUIDE

The variety of work methods, loads handled, frequency of exertions and worker characteristics which modify risk of injury in manual materials handling is virtually limitless. Careful reviews of the knowledge base regarding the hazards of manual materials handling (Herrin, et al., 1974; Drury, 1978) reveal that many facets of the problem still remain inadequately researched. The act of lifting in particular, however, has been extensively studied by many researchers (over 600 literature citations) to the extent that the hazards are reasonably well understood.

There are basically four approaches or criteria for establishing this Guide:

1. epidemiological
2. biomechanical
3. physiological, and
4. psychophysical.

In the next four chapters of this Guide each approach and the implied set of criteria are examined in detail to provide a basis for the recommendations that follow.

Epidemiology as a science is concerned with identification of the incidence, distribution, and potential controls for illness and injuries in a population. Chapter 2 surveys a number of factors identified in epidemiological studies which tend to modify risks of overexertion injuries with particular emphasis on the incidence and severity of low-back pain in industry.

Biomechanical approaches outlined in Chapter 3 show that the musculoskeletal structure (particularly the low-back) of some individuals can be overstressed when lifting compact loads of moderate magnitudes even occasionally. Further, the complex stresses to the body during manual materials handling can be predicted given a careful documentation of the specific handling task.

Physiological studies of the human body's metabolic and circulatory responses to various loads (especially with high frequency of load handling) are presented in Capter 4. Conditions which will not result in excessive physiological strain or ftaigue for a majority of workers are presented.

Psychophysical studies are designed to quantify the subjective tolerance of people to the stresses of manual materials handling. These studies, outlined in Chapter 5, indicate that a large variation exists in the working population's acceptnace of typical load handling conditions, and that combinations of certain weights and work methods are much more objectionable than others. Further, strain/sprain injuries are more prevalent for jobs requiring lifting of heavy loads. Weaker workers in terms of muscle strength (a psychophysical measure) are more susceptible to injury on these jobs than their stronger cohorts.

The large number of studies cited in this Guide indicate that a complex set of limitations exist in the working population's capability to safely handle loads of varying weights and sizes, and for various frequencies and durations during the work day.

In essence this Guide summarizes a wealth of research and presents recommendations to control the various types of hazards associated with the unaided act of symmetric (two-handed) lifting of an object of known weight and size. Quantitative recommendations regarding the safe load weight, size, location and frequency of handling are presented (Chapter 8). Factors which mitigate these recommendations are also discussed (e.g., worker training, physical fitness, strength, workplace layout, load handles, etc.). The Guide includes recommendations regarding both the selection and training of workers who must perform manual materials handling activities (Chapter 6) as well as presenting some engineering guidelines for the design of workplaces where manual materials handling is performed (Chapter 7).

CHAPTER 2

BASIS FOR GUIDE: EPIDEMIOLOGICAL APPROACH

This chapter presents a survey of recent epidemiological literature regarding short and long term health effects of MMH. Since lumbar spine disability has received much attention in research, this evidence is examined in detail. The factors which modify risk of injury are divided into job and personal risk factors. The characteristics of the job which contribute to risk are discussed in terms of weight handled, size of the load and frequency of lifting. Personal risk factors include gender, age, anthropometry, lift technique, attitude, training, and strength. The potential for preventive measures through selective matching of personal and job factors is also examined.

SHORT TERM EFFECTS OF MMH ON HEALTH

There are both short and long term health effects attributed to MMH. Short term effects include traumatic injury and fatigue. Traumatic injury to the body such as lacerations, bruising or fractures often arise during MMH due to

1. sharp or rough surfaces on the materials handled;
2. materials being dropped;
3. workers being struck by swinging loads, and other moving materials not under their control;
4. workers slipping and falling;
5. workers colliding with unseen objects;
6. mechanical stresses induced in the musculoskeletal system leading to sprained joints or torn muscles.

For injuries to the limbs and those which are superficial, the evidence is usually well documented because cause and effect are often simple to diagnose. Musculoskeletal injuries (especially to the lower back) are less clear cut and the extent of trauma is seldom defined. The interpretation of such injuries therefore depends mainly on the mechanism of injury and this (due to inexperienced, incomplete or subjective reporting) is difficult to analyze.

Traumatic back injuries may arise from the unexpected situation, the load being unexpectedly heavy or light or stuck, and from blows on the back or slips and falls (Troup, 1965; Troup, et al., 1970; Manning, 1971; Magora, 1974). In terms of the cost of medical services, productivity losses, etc., these injuries are the most serious because of the frequency with which they lead to chronic disability.

Fatigue, on the other hand, is a more prevalent short term health effect than injury in some occupations, but recovery is more rapid. Symptoms of fatigue may be respiratory, cardiovascular or muscular. Respiratory symptoms such as shortness of breath are seldom a problem in MMH except for the individual with chronic respiratory disease. In this case the worker finds it difficult to move materials in postures which restrict the movements of the rib cage.

Signs of cardiovascular stress are increased heart rate or blood pressure. Prolonged, sustained muscular activity imposes postural stresses on the muscles (particularly when bending down or carrying for any length of time) which leads to an increase in heart rate and blood pressure. High frequency, repetitive lifting elevates heart rate and blood pressure. This may be significant for the worker who suffers from the effects of hypertension or who has a cardiac disorder.

Muscular fatigue is a common cause of symptoms during and after MMH. The severity and duration of symptoms depend not only on the weight and frequency of handling but on the fitness and skill of the individual. Infrequent sessions of unaccustomed, hard work are often associated with the deposition of fibrin and a temporary peritenomyosis (Rais, 1961) which may persist for two or three days. Postural stress is also a common cause of muscular fatigue and discomfort at work (Corlett and Bishop, 1976; Wickström, et al., 1978).

LONG TERM EFFECTS OF MMH ON HEALTH

There are few epidemiological studies which relate chronic exposure to fatigue, postural stress, or musculoskeletal injury with excess morbidity or mortality. One study by Davis and Jackson (1962) identified a greater incidence of chronic bronchitis in those who regularly stooped to lift compared with those who lifted on the shoulder without flexing the trunk. Otherwise, the main long term health hazards concern the spine.

Backache due to fatigue (or postural stress), back or sciatic pain following back injury, and the early onset of degenerative disease of the spine have been cited as consequences of MMH. However, distinctions which exist between these "causes" in theory are not always distinguishable in practice. Prevention requires first, a definition of the pathological process attributable to MMH, and second the identification of the causative mechanism. The epidemiological data are at present insufficient either for a precise understanding of the pathological changes produced or to allow distinctions to be drawn even between fatigue, postural stress and injury. In practice these distinctions are difficult because:

1. There have been few attempts to analyze MMH tasks in terms of postural and handling stresses because it is a very expensive task.

2. Back pain has many possible etiologies, thus, to attribute it to a single causative factor is misleading.

3. There appear to be various "conditioning" factors (individual and environmental) which predispose a back to injury.

Not surprisingly, many authors have found it epidemiologically expedient to lump together all reported episodes of back pain attributable to work irrespective of diagnosis or cause.

BACK PAIN

Back pain can be defined as primary or secondary (Wyke, 1976). Primary back pain arises directly from the tissues of the back which are in a state of neurological, mechanical or biochemical irritation because of fatigue, postural stress, injury or local pathological change such as degeneration. It can arise from any of the tissues supplied by nociceptor afferents (i.e., practically every tissue except for the intervertebral disc and the facets of the apophyseal joints). Back muscles and fascia, vertebral ligaments, apophyseal joint capsules, the spinal dura and dural root sleeves, the adventitia of blood vessels and the periosteum all receive a nerve supply and may become primary sites for back pain. The cartilaginous facets of the apophyseal joints, the end-plates, the nucleus pulposus or the annulus fibrosus (except where it is in contact with the longitudinal ligament or periosteum) are not primary sites.

Secondary back pain is caused by a lesion which affects the nerve supply to the tissues of the back. Thus a mechanical derangement of the spine (for example, any of the degenerative processes affecting the disc or apophyseal joints) which leads to irritation or ischaemia of the posterior primary ramus or nerve degeneration in its fibers may be an indirect or secondary cause of back pain. This is analogous to the derangement of the lumbar spine (such as a prolapsed intervertebral disc) which mechanically compromises a nerve root by stretching it or angulating it from its normal path and which may cause pain, weakness or numbness in the lower limb in the area of distribution of that nerve root (Murphy, 1977; Marshall, et al., 1977).

Back pain is seldom well localized. When severe, it may be referred down the buttocks and thighs without actual root involvement (Mooney and Robertson, 1976; McCall, et al., 1978). It cannot be measured since the severity of pain actually experienced has no direct relationship either to the intensity of nociceptor activity or to the underlying pathological process (Wyke, 1976).

A truly accurate identification of the site and origin of back pain is seldom easy. The tissues concerned are usually deep from the skin surface. The quantity of pain felt and the sites from which it may arise are not closely related. And because of the absence of a nerve supply, the disc and the joint-facets may be injured without causing pain. Often the pain after back injury only begins after the secondary effects of the injury and the ensuing irritative state spread to neighboring structures.

The radiological appearance is seldom of great help in identifying the site and origin of pain. Any observed abnormality such as disc degeneration, a congenital defect or any other structural derangement is likely to be present both before the onset of pain and after its relief. Such changes have frequently been seen in people who have never had back pain.

Although it is widely believed that disorders of the lumbar intervertebral disc may be the most common single factor to which back and sciatic pain may (directly or indirectly) be ascribed, there are a growing number who consider that disorders of the apophyseal joints are of equal importance. It is misleading to select a single factor for the etiology of back pain. Many possible contributory factors must be borne in mind, for example:

1. fatigue
2. postural stress
3. trauma
4. socio-economic and emotional stresses
5. personality
6. degenerative changes
7. congenital defects
8. reduction in the size and shape of the spinal canal and intervertebral foramina
9. genetic factors
10. stretching, angulation, compression or adhesion of nerve roots
11. neurological dysfunction
12. the duration of symptoms
13. physical fitness
14. body-awareness

This list is far from complete. Further, it does not fully convey the complexity of the problem which is compounded by the way in which these contributory factors interact. Another problem in applying epidemiological data obtained from medical clinics is the knowledge that the patients who are seen in practice only represent a small fraction of the affected population (Westrin, 1973).

With regard to the "conditioning" factors which predispose the back to injury, mention has been made of environmental and individual factors; the latter include the psychosocial stresses associated with accidents at work (Hirschfeld and Behan, 1963). This is a subject to which scientific attention has only recently been turned. It concerns the mechanical and pathological factors which affect the dynamic response-characteristics of the spine and thus its capacity to withstand trauma. The strength of the tissues of the spine is inversely related to the duration of applied stress (Pery, 1957; Kazarian, 1972; Kazarian and Graves, 1977; Lamy, 1978). The dynamic response-characteristics vary with time, partly due to the "creep-effects" which take place whenever the compressive loading exceeds the osmotic pressure in the tissue. For example, a shoulder load of as little as 9 kg (20 lbs.) on healthy young adults caused measurable losses of vertebral height within 20 minutes, the loss of height being greater in the morning than in the evening. Recovery of height on removal of the load took about 10 minutes (Fitzgerald, 1972).

A similar effect is produced by vibration, "vibrocreep" being an acceleration by vibratory stress of the creep effect induced by static loading (Kazarian, 1972). Prolonged loading of the spine due to postural or vibratory stresses leads first to a reduction in height of the vertebral column; to a consequent change in the dynamics and kinetics of the apophyseal joints and of the ligaments and muscles which control them; to a reduction in the compliance of the spinal unit (Kazarian, 1975); and to changes in the transmissibility of stresses along the spine (Mertens, 1978). These changes alter the susceptibility to injury which accordingly varies throughout the working day in a way which depends on the pattern of spinal stress to which the worker is exposed.

The presence of degenerative changes in the disc affects its deformation under load (Rolander, 1966). The rate of creep depends on the grade of degeneration. Degenerated discs display a higher creep rate and a greater deformation which reaches a state of equilibrium more rapidly (Kazarian, 1975). However, there is no way in which the onset of disc degeneration can be detected in the living. It is only visible radiologically at a comparatively late stage. Though the process is usually symptom-free, its presence (with the associated changes in dynamic response to loading) must be accepted as a potential but unseen "conditioning" factor which alters susceptibility to injury. Kazarian (1975) found that recovery from creep-effect was inversely related to the duration of loading, taking as long as 20 hours. With a more rapid creep rate and greater deformation in the degenerated spinal unit, it could be deduced that for a given loading duration the degenerated segment takes longer to recover. It must therefore be concluded that some levels of postural stress may have a chronic, cumulative effect. Likewise exposure to vibration and other forms of kinetic stress while under static load may not allow a full recovery overnight.

One of the most common types of reported back injury is of sudden back pain while stooped to lift. In such cases there is no way to distinguish the long term effects of MMH from the short term effects of postural stress of injury, given our present knowledge.

JOB RISK FACTORS

Many aspects of the physical act of manually lifting a load have been identified as potentially hazardous to a person's musculoskeletal system. Among those cited in a review of the literature by Herrin, et al., (1974) are:

1. Weight - force required
2. Location/Site - postiion of the load center of gravity with respect to the worker
3. Frequency/Duration/Pace - temporal aspects of the task in terms of repetitiveness of handling
4. Stability - consistency in location of load center of gravity as in handling bulky or liquid materials
5. Coupling - texture, handle size and location, shape, color, etc.
6. Workplace Geometry - spatial aspects of the task in terms of movement distance, direction, obstacles, postural constraints, etc.
7. Environment - factors such as temperature, humidity, illumination, noise, vibration, frictional stability of the foot, etc.

To date only the first three aspects have received sufficient attention in lifting injury research to form a strong basis for guidance.

Weight Lifted

The weight of the material handled is perhaps the most obvious factor which modifies risk of injury. Hult (1974), Kosiak (1968), Lawrence (1969), Magora (1969, 1970) and Rowe (1969, 1971) are but a few of the authors who have found that the frequency of low back injuries is greater in "heavy" than in "light" industries. Many of these injuries occur when individuals lift objects which are familiar in size, shape and weight (Herndon, 1927; Brown, 1958). This is one reason some researchers believe the expenditure of time and effort in the training and education of industrial workers in good lifting technique has been to little or no avail in back injury abatement (Brown, 1972; Snook, 1978).

In most previous studies, jobs have been simply classified as heavy, medium or light work. When referring to low back stresses, a job classified as light or sedentary by traditional criteria (i.e., caloric costs to perform the job) still may require the person to lift 30 to 50 kilograms a few times during a work shift. Depending on the size of the object and body postures assumed, these infrequent acts could produce injurious mechanical stresses on the low back.

Studies by Chaffin and coworkers confirm the relation between weight handled on a job and musculoskeletal injuries. The first study (Chaffin and Park, 1973) monitored 400 workers for a one-year period. It was concluded that the

> "lifting of loads greater than about 35 pounds (16 kg) when held in close to the body, or equivalent conditions, such as 20 pounds (9 kg) between 25 and 35 inches (64 and 89 cm) in front of the body, would be potentially hazardous for some people."

This conclusion was based on both on-the-job and off-the-job low-back pain incidence rates.

In a follow-on study (Chaffin, et al., 1977) of 550 workers for a two-year period it was found that heavier jobs (in terms of maximum load lifted) also resulted in increased severity of injuries in terms of total lost workdays or medical work restriction days. In general, load handling of less than about 20 kilograms resulted in relatively few incidents of a severe strain or sprain diagnosis, but the heavier load handling jobs were associated with more severe sprains, joint dislocations and bone fractures.

Ayoub, et al., (1978) established job severity indices for workers based upon job demands which include weight handled, box size and frequency of lift. In a study of 220 males and 24 females employed on 63 lifting jobs, they found an increase in the incidence and severity of musculoskeletal disorders as these job severity indices increased.

Location/Size of Load

The physical dimensions of the load handled are important from a biomechanical, physiological, and psychophysical point of view. In studies referred to above, Chaffin and co-workers combined the weight, horizontal and vertical location of the object handled into an index of job stress referred to as a "lift strength rating." The value of this rating ranged from zero, when little or no lifting was involved, to 1.0 where the lifting was such that only a very strong person could perform the job due to excessive weight or awkward posture.

In the first study, the incidence rate of low-back pain was strongly correlated with the lift strength rating. In the moderate-strength-requiring jobs, where a potential hazard first appeared to exist, weight lifting was an equally serious hazard for both men and women. In the follow-on study (Chaffin, et al., 1977), it was observed that

> "the more remote the load center of gravity from the body (due to either the bulk of the object being handled or the workplace layout), the greater the frequency and severity of musculoskeletal problems and contact injuries."

The etiological basis for these findings will be discussed in Chapter 3.

Frequency

The relation of frequency, duration and pace of lifting to back injury potential was also studied by Chaffin, et al., (1977). High frequency load lifting was related to increased injury rates. In particular,

> "the more frequent the lifting of maximal loads on a job, the greater the frequency and severity rates of musculoskeletal problems (other than backs) and the greater the severity of contact injuries."

These results suggest

1. a greater exposure to physical stresses during repetitive lifting which could accelerate "wear and tear" in connective tissues,

2. a greater potential for muscle fatigue with repetitive lifting, and

3. a greater probability of an uncoordinated muscle action during a lift.

The physiological and psychophysical implications of these results are discussed in detail in Chapters 4 and 5.

PERSONAL RISK FACTORS

The capacity to perform the physical act of lifting varies considerably not only from individual to individual but within any given individual over time. Furthermore, the limitations of this capacity are complex and interrelated. Understanding the relationship of these characteristics to the resulting risk of injury to the worker is prerequisite to the development of schemes for placing people in jobs which do not compromise their health and safety.

Gender

The literature reveals that the gender of a worker may be related to the risk of overexertion injury. As mentioned in Chapter 1, both the ILO (1967) and more recently the U.S. Department of Labor (1970) recommended that women not lift as much as men. It appears to be accepted that, on the average, a woman's lifting strengths (primarily arms and torso strengths) are about 60% of a man's according to Asmussen and Heeboll-Neilson (1962), Chaffin (1974), Snook and Ciriello (1974b) and Petrofsky and Lind (1974). Furthermore, the biomechanical linkage mechanism (while lifting) may differ between males and females with respect to the lever systems employed, as reported by Tichauer (1973). Hence, if asked to handle a given load, the average women is more highly stressed than the average man relative to their strengths. However, the range in the strength of males and the strength of females is very large. Gender, thus, becomes secondary to the strength factor per se. Strength as a risk factor will be discussed later.

Brown (1974), in a survey of industrial workers, reports that women appear to have larger relative numbers of complaints than men when required to perform heavy, physical jobs. Magora (1970) reports a similar result. In a test of this, Chaffin and Park (1973) studied both men and women performing equally demanding, light-to-moderate load handling jobs and reported equal incidence of low-back pain cases. However, the women in this study who performed moderate materials handling jobs were stronger than the women on the lighter jobs (i.e., an unknown selection process was operating).

Age

As with gender, age has often been considered before placing people on jobs requiring the manual handling of materials. In practice, advanced age if often used in restricting a person from load handling jobs. In fact, this is mainly based on speculation, namely that older workers have diminished capacity to withstand physical stresses (Aberg, 1961). The literature indicates the greatest incidence of low-back pain (LBP) occurs in the 30 to 50 year old group (Herndon, 1927; Hult, 1954; Kosiak, et al., 1968, Magora and Taustein, 1969; Rowe, 1969 and Brown, 1973). Whether this is because older workers are not as likely to be exposed to the injury producing stresses of manual materials handling, or whether only those older workers who have survived a rigorous history of earlier stresses remain in the workforce is not clear. It appears, however, that heavy physical work, even when performed in the twenties, can cause accelerated rates of injury (Blow and Jackson, 1971). Clearly, age and aging have a complex effect on many attributes necessary for workers to safely handle heavy loads.

It seems likely that the younger person may not have developed the requisite abilities to recognize and control the hazards of manual materials handling as has the older worker. He may be overly stressing his body, yet may have the strength to withstand the rigor of the job. On the other hand, the older individual, while having perfected his skills in handling heavy or cumbersome loads, is likely to have some diminished physical capabilities. Age must, therefore, be viewed as a potential risk factor but the exact form of this risk is not yet fully understood.

Anthropometry

Body weight and stature are two anthropometric attributes with potentially complex effects on an individual's risk of injury during manual materials handling. It is generally accepted that body weight has a direct effect on the metabolic energy expenditure rate of a person while lifting and carrying loads (Kamon and Belding, 1971; Garg, et al., 1978. Thus, a heavier person would have a greater metabolic rate and concomitant circulatory load, which could lead to earlier fatigue (Petrofsky and Lind, 1974), or cardiovascular problems if the person were so predisposed. On the other hand, a heavier person is usually stronger than his lighter counterpart and usually has the mass necessary to counter-balance the handling of large objects (Snook and Irvine, 1967; Troup and Chapman, 1969 and Konz, et al., 1973). Also, Ayoub et al. (1978) found that there appears to be a relationship between body size and ability to lift. No direct link between back pain or overexertion injuries and worker body weight has been drawn.

Tauber (1970) indicated that taller people have more low-back pain incidents than shorter people. Three separate epidemiologically oriented studies by Hult (1954), Rowe (1971), and Chaffin and Park (1973) have not been able to support the notion that either fat or thin or tall or short people are at a significantly higher risk of low-back injury.

In brief, the selection of people for materials handling jobs based on their anthropometry is not well justified in terms of reducing low-back pain incidence rates. There is, however, the need to specifically consider a person's anthropometry in relation to the physical characteristics of the prospective workplace in terms of reach and mobility. All jobs that do not allow for a large range of anthropometric variation in the population, as stated in reference books such as VanCott and Kinkade (1972) and Damon, et al., (1966), should be identified and those specific function limiting dimensions should be stated in the job descriptions.

Lift Technique

A substantial amount of literature has been published on lift technique as an individual worker skill for minimizing injury. Unfortunately, no controlled epidemiological study has validated any of the contemporary theories on the subject. Proponents of the erect back, squat lift posture predicate their views on a simplistic mechanical logic; namely that this posture allows the load to be held close to the torso and, therefore, the spinal bending moment and compression forces on the back will be small. In addition, the stresses on the vertebrae will be better distributed, e.g., Floyd (1958), Davis (1959), Muchinger (1962), Himbury (1967), Anderson (1970) and Nachemson (1971). In such analyses, little concern is shown for the dynamic loadings on both the back and the knees during the lifting sequence, not withstanding the practical fact that many heavy objects are too large to be lifted between the knees, as is required by the squat lift method.

Research by Clark and Russek (1958), Brown (1973), Jorgensen and Poulsen (1974), and Garg (1976) disclose that leg lifting from a squat position is metabolically more demanding, thus possibly leading to more fatigue related injuries (e.g., slips and falls, or dropping of object). Chaffin (1969) found that the location of the load relative to the back is more important than the lifting posture in generating high compressive forces in the spine.

Confounding the issue of which posture is the safest for lifting is the realization that low-back pain can occur due to sudden slips and the resulting postural corrections necessary to regain balance (Hult, 1954; Brown, 1958). Therefore, to protect the back as well as other body segments, one must maintain a posture which assures a maximum stability over the period of the activity. Toward this end, the National Safety Council (1971) and the International Labor Office (1967) have chosen to emphasize the kinetic method of lifting, which is based upon the squat lift approach and the efficient use of body weight. However, Anderson (1970), the original developer of the kinetic method, believes that

> "it is safer to allow workers to use their own common sense and muscle sense than to teach them new drills in performing certain jobs in which a series of predetermined positions must be consciously assumed."

Observations of workers experienced in the handling of heavy loads show that the squat lifting posture is rarely used (Shephard, 1974). Davis, et al., (1965) suggested this is because the method is impractical. The leverage exerted by the quadriceps muscle in this posture is ineffective and the average worker cannot develop sufficient force to raise heavy loads. For loads away from the body, Park and Chaffin (1974) have shown that forces on the erector spinae muscles and the lumbosacral disc can be as much as 50% higher when using the recommended squat posture compared to the stooped posture. However, for compact objects close to the body, they recommend the squat method based upon a shorter moment arm for the body weight and the load acting at the lumbosacral L_5/S_1 disc.

Attitude

The characteristics of a worker's personality which may increase susceptibility to the hazards of manual materials handling are not easily measured or interpreted. Studies by Blow and Jackson (1971), Magora (1969, 1970) and White (1966) conclude that the psychosomatic aspects of low-back pain cases need further research study. Unfortunately, personality characteristics are often confounded with other demographic or anthropometric variables such as age, training, or experience. Clear evidence of how worker values and job satisfaction contribute to risk does not exist.

Training

The importance of training and work experience in reducing hazard is generally accepted in the literature. The lacking ingredient is largely a definition of what the training should be and how this early experience can be given to the naive worker without harm. Lacking strong epidemiological support at the present time, this topic is deferred to Chapter 6 where the criteria for improved training are addressed in detail.

Strength

Over the last few decades a large amount of strength data has been gathered on various populations from Olympic athletes to infant toddlers. There has also developed an awareness that strength assessments could be useful in determining personal risk of injury to a person assigned to materials handling activities. Kraus (1967) believed that strength tests should be an essential part of pre-employment examinations. Such a policy has also been advocated by Hanman (1958), Koyl and Hanson (1969), Kelly (1975) and Chaffin, et al., (1978).

Epidemiological support for strength testing as means of matching worker capabilities and job demands is provided from several studies.

Rowe (1971) found that abdominal weakness correlated with increased incidence of low-back pain. From the biomechanical point of view (Chapter 3) abdominal strength is a major factor in reducing the compressive forces acting on the lumbar spine during lifting (Davis, 1959; Bartelink, 1957; Alston, et al., 1966; and Morris, et al., 1961). Further, Troup and Chapman (1969) and Poulsen and Jorgenson (1971) believe the strength of the back extensors are of primary importance in protecting the back during manual materials handling.

A study by Chaffin and Park (1973) monitored 400 newly hired employees to determine whether medical incidence rates were related to the relative match of job requirements to strength ability. Volunteer new hires participated (anonymously) in a battery of isometric strength tests and were then monitored for one year for all medical injury experiences. A sharp increase in the mean low back pain incidence rates (by a factor of 3:1) was observed for those jobs populated by individuals who had not demonstrated strengths equal to or exceeding that required by their jobs.

Because of the importance of this result, a second longitudinal study (Chaffin, et al., 1977), was undertaken to determine if the results were reproducible. This study included another 550 workers in both light and heavy industries. All persons were strength tested as described earlier before being placed on their jobs.

Again, the incidence rate of back pain episodes was found to be almost three times higher in the overstressed group than in the understressed. For strains, sprains, dislocations, and fractures involving other than the back, strength alone did not correlate well. However, for frequent lifting an increased incident rate and severity rate resulted. Furthermore, contact type incidences such as lacerations, bruises, and abrasions of a traumatic nature increased in frequency and severity for weaker workers placed on high strength demanding jobs. It was concluded that

> "overstressing a person beyond their demonstrated strengths cannot be tolerated by a person's musculoskeletal system, especially when such exertions are performed more often than about 100 times each week. This appears true whether the medical costs are measured in terms of back injuries or more generally in terms of musculoskeletal or trauma related injuries."

Snook (1978) surveyed the strength requirements on Liberty Mutual Insurance Company policyholder jobs. From a sample of 191 compensable low-back injury claims, it was revealed that

> "...approximately one-quarter of policyholder jobs involve manual handling tasks that are acceptable to less than 75% of the workers (in terms of strength required); however, one-half of the low back injuries were associated with these jobs. This indicates that a worker is three times more susceptible to low back injury if performing a manual handling task that is acceptable to less than 75% of the working population. This also indicates that, at best, two out of every three low back injuries associated with heavy manual handling tasks can be prevented if the tasks are designed to fit at least 75% of the population. The third injury will occur anyway, regardless of the job. The other low back injuries not associated with heavy manual handling tasks will also occur. Therefore, it can be concluded that the proper design of manual handling tasks can reduce up to one-third of industrial back injuries."

The study also examined worker selection and training practices and concluded

> "No significant reduction in low back injuries was found in employers who used medical histories, medical examinations, or low back x-rays in selecting the worker for the job. Similarly, no significant reduction in low back injuries was found in employers who trained their workers to lift properly."

The topic of muscle strength and capacity is thus an important one. Chapter 5 is devoted to a detailed discussion of worker strength capability as a basis for job design.

SUMMARY

A wealth of literature can be identified which relates manual materials handling to musculoskeletal injuries in the workplace. With particular reference to low-back pain, this chapter presents an overview of but a few studies. More extensive bibliographies can be found in Brown (1972), Herrin, et al., (1974), and Drury (1978).

Due to the problems of measurement and interpretation of the "low back pain syndrome" it is recognized that longitudinal studies provide the most reliable estimates of hazard and risk. It is concluded from recent longitudinal studies that heavy load lifting contributes to increased frequency and severity rates for low-back pain. This is true regardless of the repetitive or dynamic nature of the lifting. If, however, such lifting is performed repetitively, the medical hazard extends beyond low-back problems to other musculoskeletal strain/sprain injury risk, particularly for weaker workers.

In this latter regard, gender, age, and anthropometry are known to modify these risks for populations of workers. The inherent variability between workers and within any worker over time preclude the use of such factors to assign risk to any particular individual. Strength testing, however, is supported as one means for identifying high risk workers who need to perform manual materials handling. Studies to carefully document the effectiveness of this form of selection procedure, however, are still needed.

CHAPTER 3

BASIS FOR GUIDE: BIOMECHANICAL APPROACH

The general concern in occupational biomechanics is to determine with given precision what a person can physically (mechanically) do. This concern leads one to ask more basic questions regarding the individual's health status (i.e., history of injury, disease, nutrition, etc.) and what specific tasks the person is required to physically perform in a job. In the industrial setting, this means that the person's physical capabilities must be assessed along with the physical demands of a prospective job. In addition to the simple ability to perform, biomechanics is concerned with those physical attributes of the individual and job that have been found to produce potential harm to the musculoskeletal system. As discussed in the first two chapters of this Guide, injury statistics have resulted in a major research emphasis being placed on understanding how the act of lifting loads adversely affects the health of a person's low back. This chapter, therefore, concentrates on the biomechanics of the low-back as a basis for a load handling limit.

OCCUPATIONAL BIOMECHANICS OF LOAD HANDLING

It is a well-established fact that the stresses induced at the low-back during manual materials handling are due to a combination of the weight lifted and the person's method for handling the load. Specifically, the load held in the hands as well as the person's body masses (when acted on by gravity) create rotational moments or torques at the various joints of the body. The skeletal muscles are positioned to exert forces at these joints in such a manner that they counteract the moments due to the load and body weight. From the mechanical stress standpoint, it is unfortunate that the muscles are positioned as they are, since they act through relatively small moment arms. This means that they can produce large motions with small degrees of shortening but for any external load operating on the body, high muscle and joint forces are produced.

For example, consider the major elbow joint flexor muscles (i.e., the brachialis and biceps brachii) illustrated in Figure 3.1. For the static conditions (such as holding an object),

$$T_M = T_L \text{ (i.e., the muscle and load torques are equal).}$$

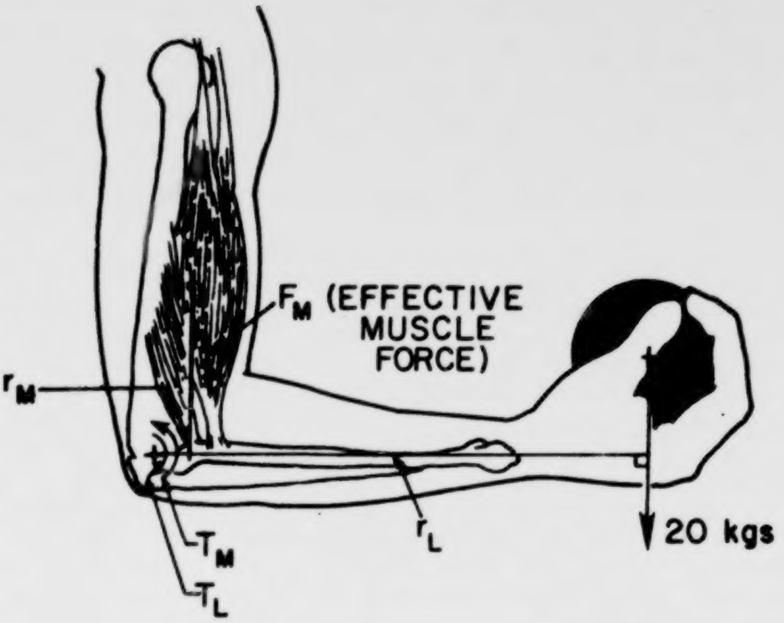


Figure 3.1: Illustration of Muscle Mechanics (Chaffin, 1975).

In terms of forces and moment arms, then

$$F_M \times r_M = 20 \text{ kg} \times r_L$$

With average male anthropometry r_M = 5 cm and r_L = 35 cm.

Therefore

$$F_M = 140 \text{ kg}$$

The weight of the forearm and hand would cause an additional 34 kg-cm moment for a total muscle force of 174 kg. Thus, simply holding a given load in the hands requires more than 7 times greater elbow flexion muscle force due to the mechanical disadvantage of the muscles.

To apply this concept, consider that a 20 kg (44 lb.) object must be lifted with both hands (10 kg in each) from the back of a shelf placed at about shoulder height. Figure 3.2 illustrates the posture. Note first that the elbow is extended, which reduces the flexor muscle moment arm to about 25% of its former value (i.e., r_M now is about 1.2 cm for an average man).

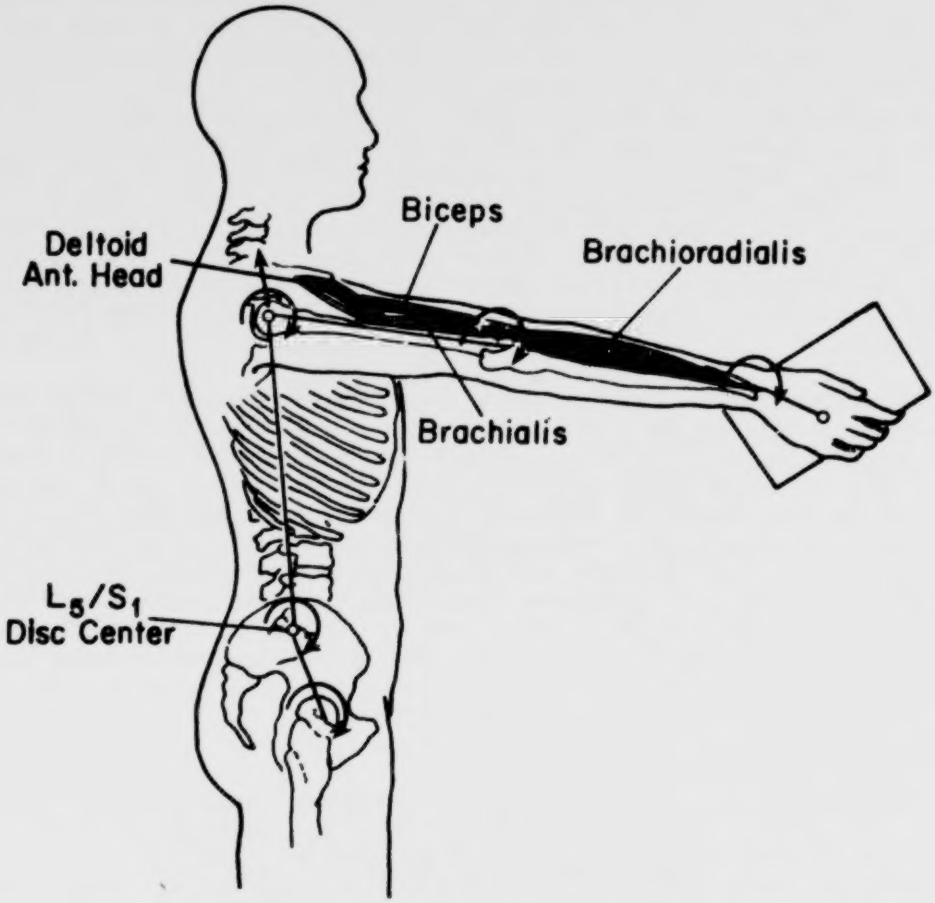


Figure 3.2: Illustration of Leverage on Shoulder, Elvow, and Lumbosacral Joints (Chaffin, 1975).

This means that the 10 kg acting on each hand requires about 292 kg of force in the elbow flexor muscles (not inclusing the extra load imposed by the weight of the forearm and hand). One might think that this muscle force is acceptable because muscles develop most tension when stretched. This is an important mechanical fact. The muscles may, indeed, be capable of producing such high forces, but what about the bones, joint cartilage and joint connective tissues? For instance, when the muscles pull across an extended joint, they compress the joint with about the same magnitude of force. This coupling of the muscle and bone compression forces is an important concept when considering low-back biomechanics. In addition, high muscle forces inhibit blood flow, placing extra stress on the heart and leading to early muscle fatigue.

Another biomechanical fact illustrated in Figure 3.2 is a large shoulder torque (and therefore shoulder muscle flexor force) produced due to the load acting through a large moment arm. The average male arm length is about 63 cm to the center of grip. This means that each shoulder torque is about 630 kg-cm (i.e., 63 cm multiplied by 10 kg). If one includes the weight and distribution of the masses of the arm, this value becomes closer to 734 kg-cm. Empirical investigations have found this torque exceeds the voluntary strength capabilities of 90% of the female industrial population and about 40% of the male industrial population (Chaffin and Baker, 1970; Martin and Chaffin, 1972). The major point, then, is that the shoulder joint is not well suited to withstand high forces when flexed or, as discussed by Tichauer (1978) when abducted.

One might suspect that such lifting requirements do not exist in industry today. One example of exactly this situation is shown in Figure 3.3. The layout of many machines, materials handling equipment and storage devices often compels the operator to assume biomechanically awkward and potentially injurious postures. Because the required posture has caused the worker to be straining himself close to his expected arm and shoulder strengths, any sudden slip of the object either could cause an overstrain injury or the object could fall onto the worker's foot. (This also illustrates the mutual concern for both health and safety in most operational situations.)

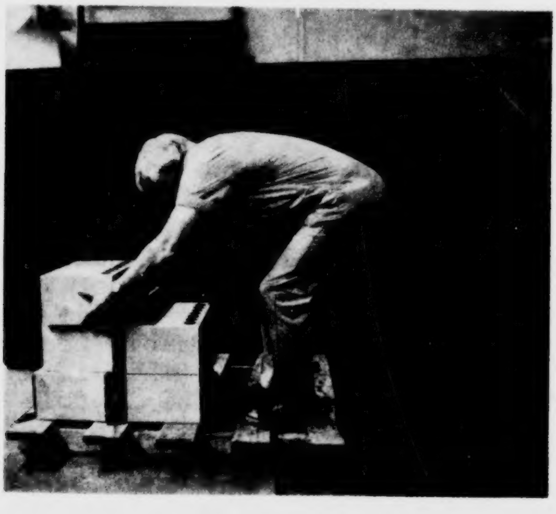


Figure 3.3: Illustration of lifting task requiring high arm and shoulder strengths

LOW BACK STRESS

Perhaps the most important point to be gleened from Figures 3.2 and 3.3 is that when a 20-kg load is held at arm's length, it produces a large torque at the lumbosacral joint of the back. For the average man's anthropometry, such a load produces more than 1200 kg-cm torque. This, in combination with the torso weight, produces a compression force at the L_5/S_1 disc equivalent to what holding about a 40-kg load between the knees would produce. In other words, one does not have to "bend over" to produce high forces on the low-back structures. A person with strong arms and shoulders, in particular, can position the body in postures that greatly multiply an external load's effect on the low back. The biomechanical consequences to the low back will now be considered in more detail.

The lumbar spine can be thought of as a set of small links with flexible articulations (discs) between each. With proper geometric and physiologic data, the forces in each disc during a specific lifting activity can be predicted. Because the clinical and biomechanical data indicate the greatest problem to be at the lower lumbar spine, the L_5/S_1 disc (lumbosacral joint) has been used to represent the spinal stresses of lifting in earlier studies by Morris, Lucas and Bresler (1961), Tichauer (1966) and Chaffin (1969). These models have clearly shown that during weight lifting, the bending moment at the lumbosacral joint can become quite large (on the order of 2000 kg-cm when lifting about 50 kg from the floor). To counteract this moment, the muscles of the low-back region (primarily the erector spinae group) must exert correspondingly high forces, since they operate on small moment arms (about 3.8 - 5.0 cm, as referenced by Chaffin and Moulis (1969) and shown in Figure 3.4).

The high forces generated by the low-back muscles are the primary source of compression forces on the lumbosacral disc. These concepts are illustrated in Figure 3.5 for a person holding a variable load, designated F_H. The graph at the bottom of Figure 3.5 displays the predicted compression forces at the L_5/S_1 disc for increasing loads held in the position depicted, using a 50 percentile man's anthropometric data and normative abdominal assistance values (Chaffin, 1969).

The important concept in Figure 3.5 is that even in the "reasonable" lifting posture depicted, high compression forces are created in the disc. Direct pressure transducer measurements by Nachemson and Elfstrom (1970) of the compression forces in the lumbar discs have confirmed the range of these predicted values.

The maximal amount of compression that can be tolerated by the lumbar spinal column has been estimated from axial loading compression tests on cadaver columns. Data from separate studies of this type by Evans and Lissner (1959) and Sonoda (1962) disclose large biologic variations in the disc's (and its weight-

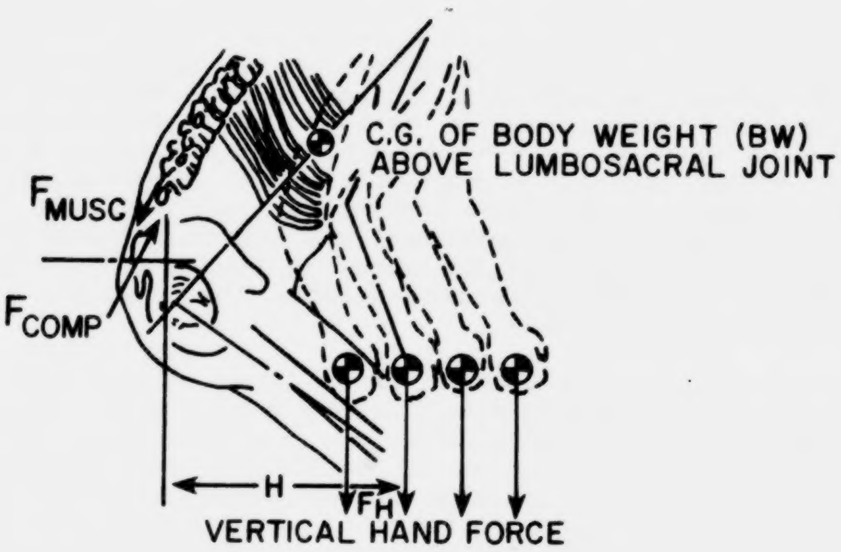

C.G. OF BODY WEIGHT (BW)
ABOVE LUMBOSACRAL JOINT
F_{MUSC}
F_{COMP}
H
F_H
VERTICAL HAND FORCE

Figure 3.4: Forces and moments operating at L_5/S_1 disc during load lifting.

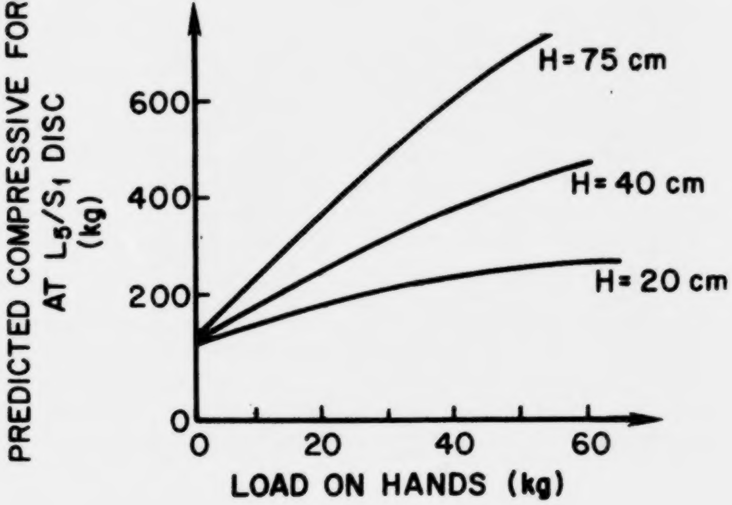


Figure 3.5: Predicted compressive forces acting on L_5/S_1 disc. (Adapted from Chaffin, 1975).

bearing cartilage end-plate's) ability to withstand such stresses. Figure 3.6 illustrates these data by age group. In general, the data from male cadavers under 40 years of age disclose a mean of about 675 kg before the cartilage end-plates begin to exhibit microfractures. The fracture levels range, however, from as low as 250 kg (over 60 years of age) to more than 950 kg (under 40 years of age). Sonoda (1962) estimates that the female's spinal compression tolerance is about 17% less than the male's. This would be consistent with the smaller force-bearing area of the vertebral bodies in a woman's spine.

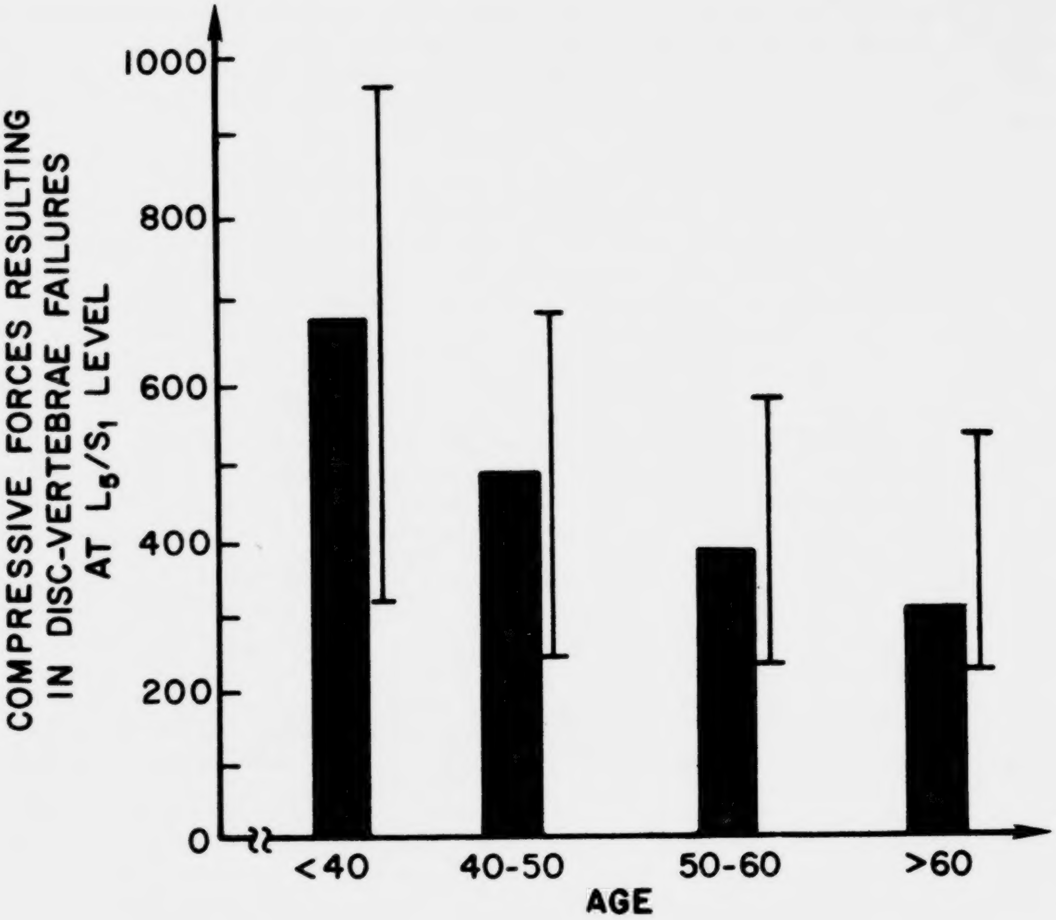


Figure 3.6: Mean and Range of Disc Compression Failures by Age (Adapted from Evans, 1959, and Sonoda, 1962).

Two further observations from these early cadaver studies are noteworthy. First, the discs themselves (if healthy) do not herniate. Instead, the cartilage end-plates that distribute the compression loads to the bodies of the vertebral segments fail, as described by Armstrong (1965). Second, the large variation in strength of the cadaver columns may indicate that the cartilage end-plates of some people were already weakened by prior stresses, with resulting microfractures and scarring. If true, this would contribute to the disc degeneration that now is acknowledged as being necessary before the more common and most serious discogenic low-back problems can develop. In other words, evidence indicates that repeated compressive stresses of life (and lifting in particular) can be sufficient enough to cause microfractures in the cartilage end-plates and subchondral bone of the vertebral bodies which (it is hypothesized) would alter the metabolism and necessary fluid transfer to the disc. If this occurs, a degenerated capability of the discs to withstand further compression loads would develop. The end result of this process is that the annulus fibrosus bulges or ruptures, causing pressure on the adjacent nerve roots, as shown in Figure 3.7.

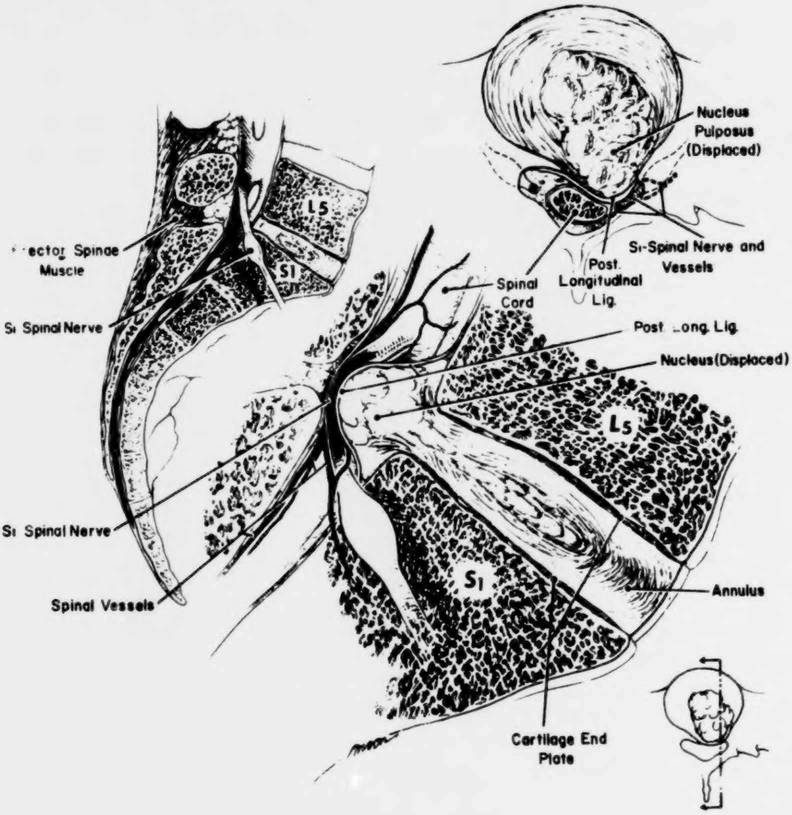

Nucleus Pulposus (Displaced)
L5
S1
Erector Spinae Muscle
S1-Spinal Nerve and Vessels
Post. Longitudinal Lig.
Spinal Cord
S1 Spinal Nerve
Post. Long. Lig.
Nucleus (Displaced)
L5
S1 Spinal Nerve
S1
Annulus
Spinal Vessels
Cartilage End Plate

Figure 3.7: Displaced degenerated disc exerting pressure on spinal nerves (Chaffin, 1975).

It is believed by Rowe (1969) that 70-80% of all chronic low-back pain will be diagnosed as discogenic after a period of repeated episodes. At the very least, degeneration and the narrowing of the disc that results from it will contribute to a more unstable spinal structure. In this latter regard, Fiorini and McCammond (1976) state: "Many damaged discs showing radiographical narrowing may not cause discogenic back pain at all if there is no disc hernation, but may cause facetogenic back pain by causing subluxation and malapposition of the interarticular joints." Some evidence that disc degeneration is accelerated by physical stresses has been developed by Hult (1954). He reported that narrowing and osteophyte development of the discs and adjacent vertebral bodies was 1-1/2 times greater in those people engaged in heavy physical labor than in sedentary workers.

The implications of this disc degeneration theory are far-reaching. Most important is that assigning cause for low-back pain cannot be based simply on the immediate circumstances at the time when the pain first developed. In fact, most low-back episodes do not suddenly start with a "jabbing pain," although these cases are easily remembered and reported by patients and physicians alike. Rather the symptoms more often are slow to develop, with stiffness, dull aching pain and finally, incapacitating discomfort, which occurs possibly hours or even days later. With this in mind, it is easy to rationalize why the statistics relating a person's physical acts to the incidence of low-back pain generally are so poor.

POSTURE EFFECTS

Returning to the biomechanical aspects of manual materials handling, several general concepts need further definition. First, there remains the issue of how a person's posture affects low-back stresses. It already has been shown that if the load is horizontally distant from the torso, large forces can result, even without bending over. Therefore, the most important rule in materials handling is to ensure that the person is able to bring the torso as close to the load center of gravity as possible before lifting it. This often requires having the person squat down beside the load with the legs straddling it when the load is on or near the floor, and lifting it between the knees. This assumes, of course, that the load is small enough to go between the flexed legs easily.

If the load is small, the companion rule regarding keeping the back near vertical is biomechanically justified, as it reduces the stresses on the low back due to the torso weight. Unfortunately, lifting with the legs from a squatting position with the back vertical (i.e., the classic recommended posture) often is not possible because the person so instructed does not have the quadriceps strength necessary to extend the knees and raise the body from such a position. In other words, most people, when lifting weights, lean their torso forward to reduce the moment on the knees. This is so common in lifting that the quadriceps muscles often are insufficiently developed to allow the person to "lift with the legs" when instructed to do so. Thus, the rule about "lifting with the legs while keeping the back vertical" must be qualified to include the physiologic fact that many people will not be able to perform such lifting without first increasing their leg strengths. In addition, with some individuals, muscle-stretching exercises will be needed to provide the necessary range of motion in the knees, hips and ankles. It should also be recognized that lifting from a squat position will require lifting of the torso, thus requiring extra energy expenditure, as discussed in the next chapter.

A second, more complex qualification on the classic "squat lift" rule must also be realized when lifting large objects that cannot pass between the knees. Studies by Park (1973) and Park and Chaffin (1974) disclose that when a large object is lifted around the front of the knees, as required in the squatting type of leg lift just described, it necessarily causes the moment arm of the load about the low back to be large. This causes the moment at the low back to be large, and hence high spinal compressive forces and muscle forces result. In contrast, the more often used stoop-back method of lifting allows the person to "move over" the weight to be lifted and thus reduce the load moment arm about the lower back. Figure 3.8 illustrates this concept. For the calculation of the forces in the example, a 15.5 kg (35 lb.) load is being lifted from a position that is 38 cm (15 inches) in front of the ankles and 38 cm (15 inches) above the floor. Nominal anthropometry and abdominal assistance values are assumed, as described by Chaffin (1975). It can be seen that the "stooped-over" position results in about one-third less compressive stress on the low back than the squatting type of lift. It should also be evident that the stooped-over position allows the person to reduce the load moment arm of 35 cm (14 inches) about the low back even further by moving in over the load more than is shown, whereas the load moment arm of 50.9 cm (20 inches) for the squat lift is as small as possible due to interference of the upper legs and the load. A further limitation on lifting large objects with a squat lift arises from the fact that the arms must be extended farther in the forward horizontal direction than with the stooped-over posture. As discussed earlier, such a position of the arms means that a high torque will be produced at the shoulders, which may not have the strength to move the load upward. Therefore, the person normally will lean forward more to lessen the load moment arm about the shoulders, and in so doing will cause greater stresses on the low back both by the effects of gravity acting on the torso mass and by hyperflexing the lumbar column. Such hyperflexion places a greater stress on the posterior positions of the annulus of the disc, thus distributing the compressive loads unevenly within the disc. As Davis and Troup (1965) have described moderate flexion of the torso does provide effective abdominal pressure assistance during lifting, thus reducing the low-back stresses. Therefore, some torso flexion appears to be

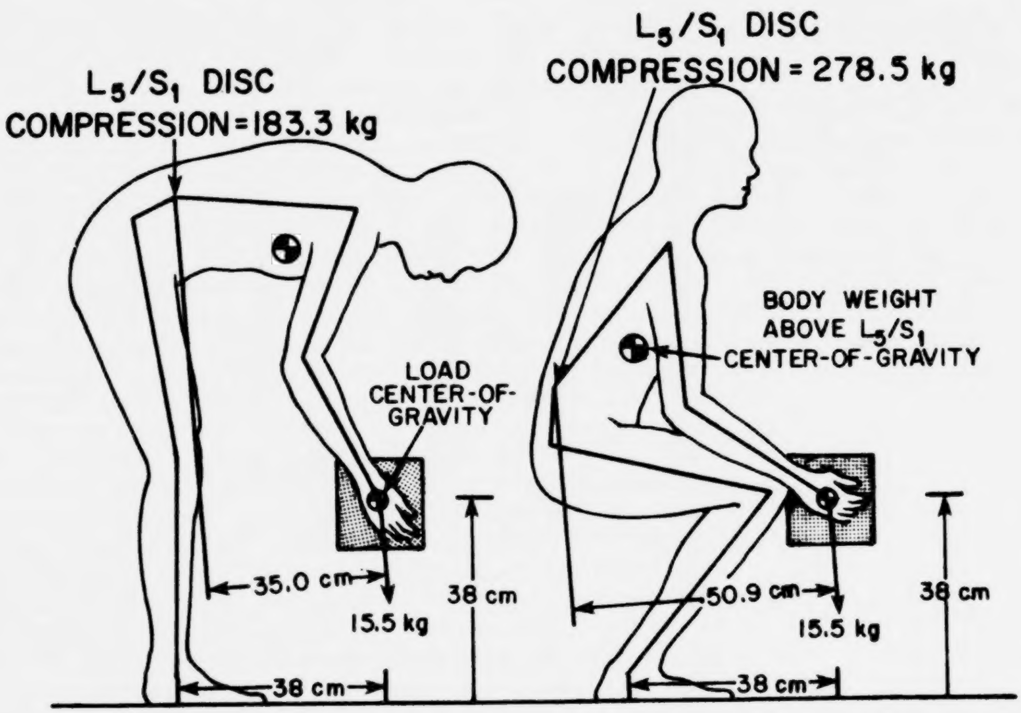

L_5/S_1 DISC
COMPRESSION=183.3 kg
LOAD
CENTER-OF-
GRAVITY
35.0 cm
15.5 kg
38 cm
38 cm
L_5/S_1 DISC
COMPRESSION = 278.5 kg
BODY WEIGHT
ABOVE L_5/S_1
CENTER-OF-GRAVITY
50.9 cm
15.5 kg
38 cm
38 cm

Figure 3.8: Low Back Compression Associated with Two Lifting Postures (Park and Chaffin, 1974).

acceptable but extreme flexion could predispose the lower back to injury when the peak load occurs, usually during the first 200 msec of the lift.

Based on simple quasistatic biomechanical concepts, one must conclude that instructions as to lifting postures must reflect concern for the person's strength and mobility as well as the size of the object to be lifted. Lifting of objects that cannot pass between the legs should be done with the traditional stooped-over torso and legs only slightly flexed. Where possible loads should be reduced in size to allow them to come between the legs. When this is possible, a squatting leg lift with the back nearly vertical is recommended. Unfortunately, these recommendations are based on biomechanical considerations only. Controlled field studies to determine the benefits associated with these recommendations have not been made. As Brown (1973) and Jones (1971) point out, much more research is necessary to establish the validity of any suggested methods of handling loads. For the present, however, biomechanically based recommendations certainly are worth serious consideration when counseling a person as to how a load should be lifted and carried safely.

ASYMMETRIC LIFTING

The preceding biomechanical discussion has considered relatively symmetric and smooth lifting of loads. Symmetric lifting, wherein the load is held with both hands in front of the body, is believed to be the most common method of handling a heavy load. This method equalizes the stresses bilaterally on the musculoskeletal system allowing a person to utilize their muscle strengths most effectively. There are situations, however, wherein moderate loads may be lifted asymmetrically. Unfortunately, the hazards of such lifting postures have not been documented in controlled field studies, but biomechanically one must be concerned. An asymmetric lift, which has the person bring the load up along the side of the body, causes not only a lateral bending moment on the lumbar column but, because of lordodic curvature of the column, produces a rotation of each vertebra on its adjacent vertebra. One laboratory study by Farfan, et al., (1970) indicates that disc degeneration most often involves the annulus fibrosus, which is the structure that provides 40-50% of the torsional resistance to twisting of the lumbar vertebrae. With disc degeneration, this torsional resistance can be reduced to less than one-half its normal strength, thus providing a significant injury potential. In addition, the asymmetric loading of the musculature of the back could produce a concentrated stress of sufficient magnitude to strain a specific muscle of the many muscles required to stabilize the column. In general, it must be concluded that lifting of loads along the side of the body is to be avoided. A person's arm and shoulder strengths are not well enough developed to lift heavy weights in an asymmetric fashion. Moderate load lifting, however, may be attempted using a side lift, and therefore instructions and job redesign often are indicated to reduce the stresses associated with such lifts.

DYNAMIC LIFTING

Another limitation regarding the present state of knowledge concerns the dynamics of load lifting. One investigation by Park (1973) disclosed that the lifting of loads between 6.5 kg (15 lbs.) and 23 kg (50 lbs.) from the floor to an erect carrying position (load against the front of the upper legs) resulted in an acceleration effect that added between 15% and 20% to the static load 100 msec after the beginning of the lift. Furthermore, with fast motions the ability of the somatic nervous system to coordinate the many muscles necessary to stabilize the spinal column is stressed. Electromyographic studies by Donish and Basmajian (1972), Tichauer (1971), Morris, Benner, and Lucas (1962) have only recently begun to identify the temporal complexities involved in coordinating the recruitment of the back muscles. It is hypothesized by Brown (1973) that some low-back problems are related to muscle fatigue, which further inhibits coordination of the back muscles. Tichauer (1966) suggests that unanticipated motions due to trying to catch falling or tossed objects can cause low-back injuries.

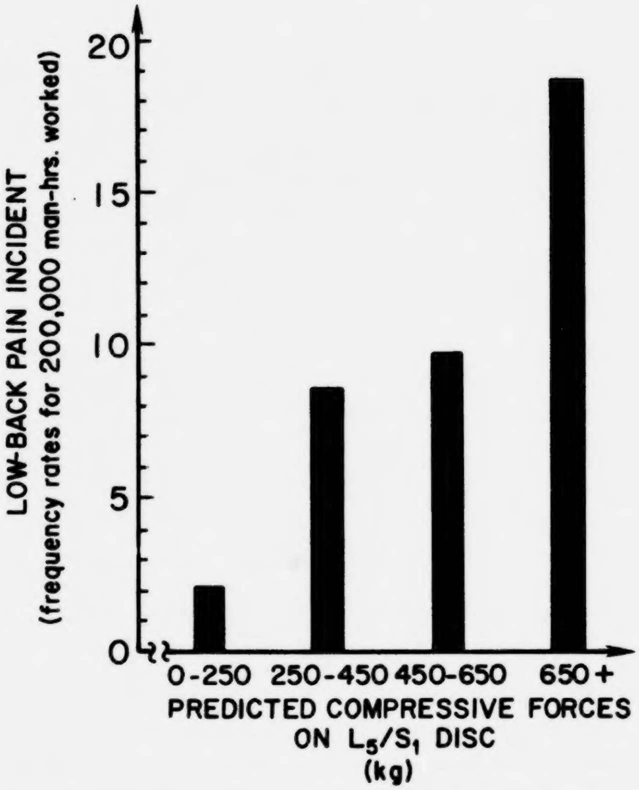


Figure 3.9: Relation Between LBP and Compressive Force (Chaffin and Park, 1973).

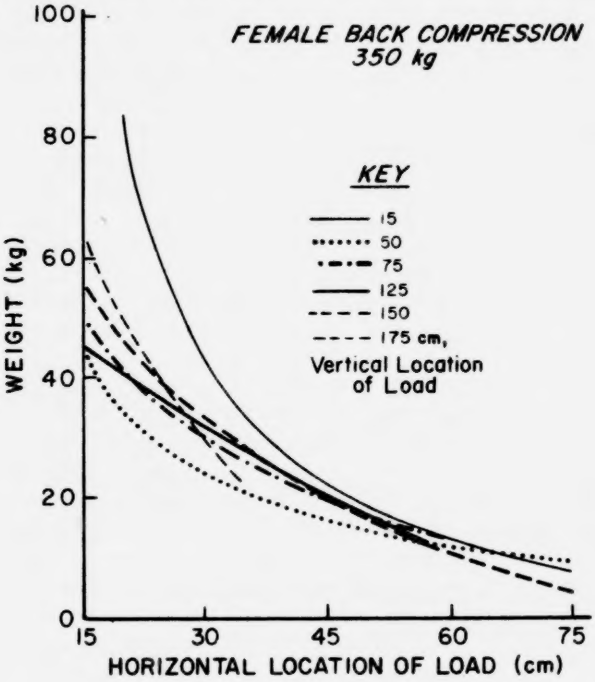


Figure 3.10: Task Variables Producing 350 kg Female Back Compression.

Clearly, dynamic actions that result in high inertial forces are more difficult for one to control. Therefore, it is reasonable to require of people who are engaged in manual materials handling that they move the loads in a smooth and well-planned manner. Further, as part of this concern is the need to provide good foot tractions and hand grips on such loads to avoid any possible slips and/or falls.

BIOMECHANICAL DESIGN CRITERIA

The biomechanics of lifting and handling loads provides one basis for why certain musculoskeletal overexertion injuries and illnesses develop. Specifically, biomechanical studies indicate that the low-back is vulnerable to continual overstress damage during even moderate load handling, but that symptoms may not manifest themselves until later in life. In essence, existing knowledge supports a "wear-and-tear" hypothesis of low-back pain, which requires that load handling activities be limited and carefully specified.

Figure 3.9 illustrates the observed incidence rates for low back pain related to predicted back compressive forces on the L_5/S_1 disc (Chaffin and Park, 1973). Based on this industrial study of 400 workers and earlier compressive tolerance cadaver studies of Evans and Lissner (1959) and Sonoda (1962) (see Figure 3.6) it is apparent that jobs which place more than 650 kg compressive force on the low-back are hazardous to all but the healthiest of workers. In terms of a specification for design a much lower level of 350 kg or lower should be viewed as an upper limit. This will not necessarily be protective for most individuals over 50 years of age or other susceptible populations. However, based on current knowledge of injuries in industrial work a lower limit is not supported at this time. This is, in part, due to historical self-selection mechanisms which have precluded weaker individuals from performing rigorous MMH.

To convert low back compression values into load limit recommendations, computerized biomechanical models which allow simultaneous analyses of the stresses placed on the many linkages and joints of the body during lifting are needed. Chaffin (1972) and Garg and Chaffin (1975) have reported a Static Sagittal Plane Lifting (SSPL) model in the literature. As the name infers, this particular model has been developed to evaluate various static situations, such as when one is holding a weight or pushing or pulling on a non-moving container. The large static component of a lift enables the SSPL model to be useful in establishing safe lifting limits. Figure 3.10 illustrates the trade-offs between horizontal (H) and vertical (V) locations of a load which would produce 350 kg compressive force on the L_5/S_1 disc of the average female based on the most recent model of Chaffin, et al., (1978). The assumed female anthropometry was reported by Dempster (1975). Horizontal location is measured forward of the body centerline from the mid-point between the ankles. Vertical location is measured from the floor or foot sole. Likewise, Figure 3.11 illustrates the same combinations which would produce 650 kg compressive force on the

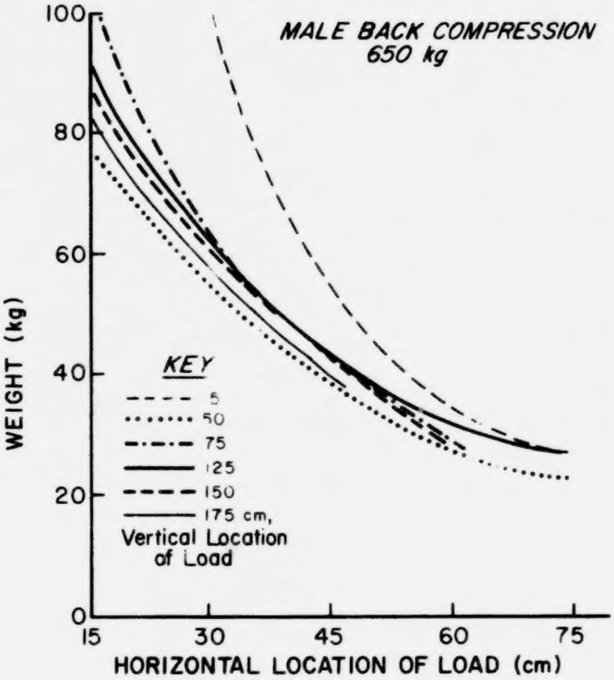


Figure 3.11: Task Variables Producing 650 kg Male Back Compression.

L_5/S_1 disc of the average male. In each case, the most advantageous posture (that producing minimal compression) is assumed for these illustrations.

These figures suggest a simple inverse linear relation between the maximum weight lifted (W) and the horizontal location of the load (H). This is,

$$W = K(1/H)$$

where K is a constant which depends on gender and vertical location of the load.

A Dynamic Biomechanical Lifting model developed by El-Bassoussi (1974) and further reported by Ayoub and El-Bassoussi (1978) also appears in the literature. This model calculates the compressive and shear forces on the L_5/S_1 disc during the time course of a lifting movement for lifts made in the sagittal plane from the floor to a height of 30 inches. The output forces of this model include a static component resulting from the respective weights of the load and body segments plus a dynamic component due to the acceleration of the same during a lift. Figure 3.12 shows the compressive and shear forces for both a leg lift and a back lift when lifting a 4.5 kg (10 lb.) load with a horizontal location of 50 cm (20 in.). It is important to note that for either type of

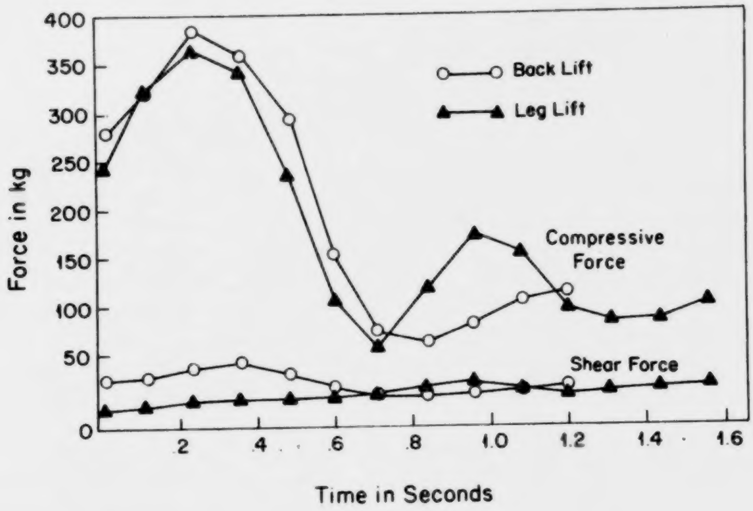


Figure 3.12: Changes in Compressive and Shear Forces on the Low Back for a Leg Lift and Back Lift During the Lifting Action

lift, the compressive force reaches a maximum after about 200 msec. Figures 3.13 and 3.14 illustrate the combination of weight and horizontal location of the load lifted which result in compressive forces of from 400 to 700 kg on the L_5/S_1 disc for leg (squat) lifts and back lifts (stooped), respectively. For each figure average male anthropometry and body segment weights are assumed. Horizontal location of the load with respect to the spine is determined using the equation $H = (W/2 + 20)$ cm, where W = width of the object away from the body.

Davis and Stubbs (1977a, 1977b, 1978), in a three-part series, expressed safe levels of manual forces for young males in various standing, squatting, sitting, and kneeling postures based on biomechanical considerations. Morris, et al., (1961) and Davis and Troup (1964) noted a correlation between magnitudes of forces acting on the lower spine during manual activity and the magnitudes of intra-abdominal pressure. Using this relationship, Davis and Stubbs monitored intra-abdominal pressure with a swallowed radio pill on 200 male soldiers while they performed the aforementioned activities.

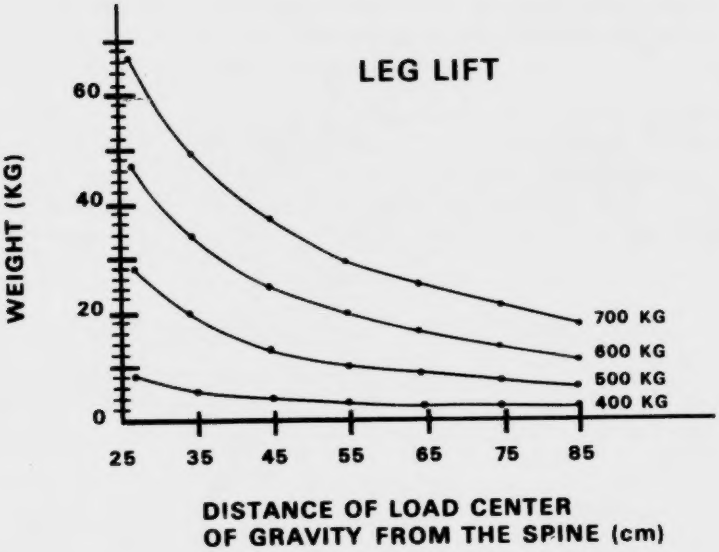


Figure 3.13: Combination of Weight and Horizontal Location of Loads Resulting in from 400 to 700 kg. Compressive Force for Leg Lifts.

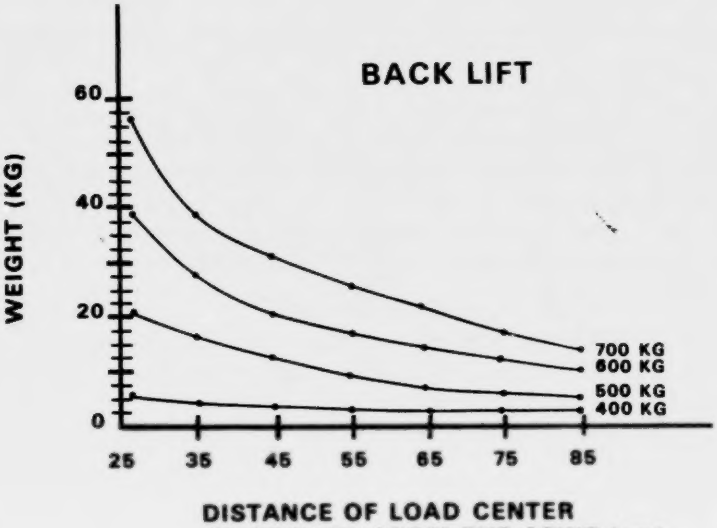


Figure 3.14: Combination of Weight and Horizontal Location of Loads Resulting in from 400 to 700 kg. Compressive Force for Back Lifts.

From this, they generated contour maps of acceptable forces while in these postures based on a maximum of 90 mm Hg of intra truncal pressure.

What is evident from the preceding section is that a biomechanical criterion (back compression tolerance) can be converted into practical recommendations for acceptable lifting task descriptions. This criterion and those of the following chapters were used to establish the guidelines for lifting which are presented in detail in chapter 8.

In terms of the biomechanics of lifting it can be concluded that:

1. Lifting a 5 kg compact load (wherein the mass CG of the load is within 50 cm of the ankles) could create compressive forces sufficient to cause damage to older lumbar vertebral discs.

2. As the load mass center of gravity is moved horizontally away from the body, a proportional increase in the compressive force on the low-back is created. Thus even light loads need to be handled close to the body.

3. When a load is lifted from the floor, additional stresses are exerted on the low-back due to the body weight moment when stooping to pick the load up. Thus heavy loads should not be stored on the floor, but should be raised to about standing knuckle height (minimum 50 cm) to avoid the necessity for stooping over and lifting.

4. The postures used to lift loads from the floor can exert a complex and relatively unknown effect on the stresses of the low-back during lifting. Specific instructions as to the safe posture to use will be necessarily complex, reflecting such factors as leg strengths, load and load size. Until such complexities are better researched, it is recommended that instructions as to lifting postures be avoided.

5. Lifting loads asymmetrically (by one hand or at the side with the torso twisted) can impart complex and potentially hazardous stresses to the lumbar column. Such acts should be avoided by instructions and workplace layouts which permit the worker to address the load in a symmetric manner.

6. The dynamic forces imparted by rapid or jerking motions can multiply a load's effect greatly. Instructions to handle even moderate loads in a smooth and deliberate manner are recommended.

CHAPTER 4

BASIS FOR GUIDE: PHYSIOLOGICAL APPROACH

This chapter is concerned with the design of repetitive lifting tasks which a person can perform without excessive fatigue. Oxygen consumption, metabolic energy expenditure rate and heart rate are the physiological measurements which have been suggested most often for determining the maximum work intensity that can be continuously performed without accumulating excessive physical fatigue.

It is convenient to consider these responses first as they are measured in the laboratory and then to place our understanding of them in the practical conditions of everyday industrial work.

There are two kinds of muscular activity. First, dynamic exercise, which forms the bulk of everyday activity, can be defined as exercise in which muscles shorten, causing movement of the bones around joints of the skeleton. Exercise such as walking, jogging, bicycling, etc. comprise almost "pure" dynamic exercise. The second type of exercise is isometric, when the muscles do not shorten and there is no movement around the joints; carrying or holding packages, suitcases, etc. are common examples. The physiological responses to these two kinds of exercise are quite different; while dynamic exercise provides a greater expenditure of energy in daily work, isometric exercise (or static effort) readily induces muscular fatigue. Daily activity is made up of both types of exercise and the physiological responses to each ought to be properly understood.

In the description of physiological responses to exercise given in this chapter, the individuals are presumed healthy. Illness or disease of many kinds can substantially modify those responses.

DYNAMIC EXERCISE

Physiologists measure this kind of exercise as the amount of oxygen that is used by the muscles. When muscles become active, their increased metabolism demands an increase in the delivery of oxygen and foodstuffs if the activity is to continue. These circumstances call for an increased respiratory function and a greater amount of blood flow to the muscles. However, these respiratory and cardiovascular responses are linearly related to the amount of oxygen used used by the muscles. In turn, the amount of oxygen used (aerobic activity; $\dot{V}O_2$) is linearly related to the amount of external work done by the muscles. Hence we can judge the severity of the exercise by the $\dot{V}O_2$. The skeletal muscles, however, have also the ability to contract even in the absence of oxygen; that anaerobic capacity is limited and is called on only when the aerobic metabolism is insufficient to allow the exercise to continue. When the limit of the anaerobic metabolism is reached, the muscles are fatigued and are no longer able to do effective work.

There is an upper limit to aerobic metabolism, often called the aerobic capacity (or in physiological jargon, the $\dot{V}O_2$ max) which varies considerably from person to person, influenced by a number of factors which are described below. Usually, the muscles' anaerobic metabolism is called into play when the exercise demands 50% or more of the VO_2 max. As the severity of the exercise increases above that level, the greater is the proportion of anaerobic metabolism for the muscular activity and, because the amount of anaerobic metabolism is finite, the duration of exercise before fatigue occurs varies inversely with increasing severity of the activity. Obviously, it is important to know what the $\dot{V}O_2$ max is for an individual or a group of individuals and also to avoid prolonged work at levels greater than 50% $\dot{V}O_2$ max if fatigue is to be avoided (In fact, lower percentages of $\dot{V}O_2$ max have been considered limiting, in some studies, as is discussed below). Factors which influence $\dot{V}O_2$ include:

1. Level of $\dot{V}O_2$ max ("fitness")

   It is well established that when men and women engage in a regimen of relatively severe exercise on a controlled repetitive basis, they are able to improve their physical performance. Their aerobic work capacity may increase by amounts reported to be between 5 and 25%; the increase appears to depend on the frequency, duration and severity of the training regimen and also on the degree of "fitness" of the individuals concerned (cf. Astrand and Rodahl, 1970).

   The level of activity of the bulk of the population is labelled as "sedentary". In the last few decades surveys have been completed on the proportion of time spent in different activities in a variety of occupations; in a number of these surveys, information has also been collected on activities during non-working hours. In light industries, much of the work done involves low levels of energy expenditure. Except in "heavy" industries such as mining, steel working, etc., the work seldom reaches or exceeds 50% $\dot{V}O_2$ max and then only intermittently.

   In these heavy industries, the work level yields an average daily oxygen requirement of about 1 l O_2/min. (metabolic energy equivalent = 5 Kcal/min). Periodically, tasks occur at much higher levels, of 2 l O_2/min (10 Kcal/min) or even as high as 3 l O_2/min (15 Kcal/min). These tasks are short, lasting only for several minutes, and to provide an average daily level of 1.0 l O_2/min, are offset by rest periods along with periods of work at low levels of oxygen usage. Even in "heavy" industries, however, the increasing use of automation tends to reduce the energy expenditure of the work. However, workers in such jobs can be regarded as "active" (or trained) in some degree and they have a greater aerobic capacity than their "sendentary" counterparts in most industries.

2. Age and Sex

The age and sex of an individual have a profound effect on the $\dot{V}O_2$ max. The decline of $\dot{V}O_2$ max with age for both sexes, can be expressed as a linear function (cf. Astrand and Rodahl, 1977; Hodgson and Buskirk, 1978). At age 60 years, an individual will have, on average, a reduction of about 30 to 40% of the $\dot{V}O_2$ max he had at 20 years; that is, there is a loss of about 10% in aerobic capacity each decade. The $\dot{V}O_2$ max at any given age for women averages about 70% of that for men.

3. Body Weight and Body Fat

The $\dot{V}O_2$ max of men who are not fat is linearly related to the body weight. The same is true for women but the relationship has a lower slope, particularly noticeable after puberty. The difference between men and women may well be due to sex differences in fat content of the body.

When the $\dot{V}O_2$ max is expressed in terms of unit body weight, the influence of age is not diminished but the variance of the results is much reduced. Treatment of the results in this way also reduces the influence of sex for a given age. When the amount of body weight that is fat is measured, the VO_2 max can be expressed as oxygen uptake per unit of "lean" body weight. That procedure further reduces the variance of the results for men and women at given ages. It diminishes but does not completely abolish the sex difference in $\dot{V}O_2$ max and does not influence the proportional loss of $\dot{V}O_2$ max with age.

4. Type of Exercise

The type of exercise used in the assessment of $\dot{V}O_2$ max influences the results. The dominant feature influencing the measurement is the mass of the muscles involved in the exercise. Thereby, running uphill provides values which are marginally greater (5 to 8%) than running on the horizontal or bicycling. Bicycling itself is reported to yield a slightly higher $\dot{V}O_2$ max at 60 rpm than at higher or lower values of rpm. Arm cranking or bicycling with both legs while simultaneously cranking with both arms does not result in a $\dot{V}O_2$ max greater than that found in running uphill; there appears to be an optimum mass of muscles which provides a $\dot{V}O_2$ max.

This matter gains importance when industrial work is considered. It has been shown that the energy cost of lifting boxes of the same weight and at the same frequency is substantially greater when the legs are bent to assist lifting than when the trunk only (cantilever) is bent (Brown, 1971; Garg, 1976). The $\dot{V}O_2$ max of lifting boxes by the cantilever method is much lower than for bicycling (Petrofsky and Lind, 1978). With boxes of 15 kg or more, the $\dot{V}O_2$ max of lifting with the bent-leg method is the same as in bicycling but when the boxes weighed 8 kg or less, the $\dot{V}O_2$ max is lower than the response to bicycling (Lind and Williams, 1979).

Depending on the nature and severity of the task, selection of workers based on their $\dot{V}O_2$ max is clearly desirable. But in many industrial circumstances, it is impractical to provide this kind of selection procedure for individuals.

ISOMETRIC EXERCISE

The methods for assessing physiological responses to isometric exercise are different from those described for dynamic exercise. At most tensions, sustained contractions readily induce local muscular fatigue, from which recovery is slow. For a given group of muscles, the maximum voluntary contraction (MVC) is first measured on a dynamometer. The bulk of experiments then report the endurance time to fatigue when specific sub-maximum tensions are held. There emerges a clear pattern of relationship between the sustained tension and the endurance time (when that tension can no longer be maintained). At 100% MVC the endurance is about 3 to 4 seconds. At 70, 50 and 30% MVC, the endurance is of the order of 35, 90, and 250 sec, respectively. When the tension falls to less than about 15% MVC, the contraction can be maintained for a long time, and results in little fatigue.

The most commonly reported studies involve hand-grip contractions, for which the MVC for men is about 50 kg, while for women it is 35 kg. There is, however, a wide individual variation in both the MVC and the endurance of sub-maximal tensions. Several factors influence both the MVC and the endurance time. Age results in a reduction of strength, but not as dramatically as it affects $\dot{V}O_2$ max in dynamic exercise. Muscle temperature does not affect the MVC but, as the muscle temperature increases, there is a reduction in endurance time. At relatively low tensions (e.g., 30% MVC) this can amount to some 20 sec for each °C difference in muscle temperature; the muscle temperature can readily vary by 5 or 6°C as a result of the influence of the environment, clothing, subcutaneous fat or previous exercise. At high tensions (e.g., 70% MVC) the difference due to temperature is not so marked.

Women have greater endurance than men at all relative tensions below 50-60% MVC. But when these results are considered in absolute terms, the reverse is true because the men are so much stronger than women. As an extreme example, at their average MVC, 36 kg, the endurance of women is only 3 sec whereas the same tension represents only 70% MVC for men who hold that tension for an average of 36 sec, or 12 times longer. At the other end of the tension/endurance curve, a tension of 7.5 kg represents 15% MVC for men and can be held for an average time in excess of 30 min (the absolute time is not known). In contrast, 7.5 kg represents 21% MVC for women and the average endurance time is about 10 minutes.

The type of muscle examined is doubtless an important determinant of endurance, but there is insufficient data to provide realistic comparisons with hand-grip contraction. The muscle mass will undoubtedly affect the oxygen uptake but has little effect on the cardiovascular responses, which provide the most dramatic differences in physiologic changes when compared to those in dynamic exercise. In rhythmic exercise there is a large increase in heart rate but little increase in blood pressure, whereas the increase in heart rate is modest with a large increase in blood pressure during isometric exercise.

The physiological responses to isometric exercise are superimposed on those due to rhythmic exercise when the two kinds of activity are carried out simultaneously. But insufficient information is available about intermittent exercise to characterize precisely that the circumstances that induce fatigue. Current evidence indicates a duration of contractions:rest ratio of 2:1 will induce fatigue at high tensions such as 60% MVC whereas a ratio of 3:1 is necessary to induce fatigue at low tensions (25% MVC).

PHYSIOLOGICAL RESPONSES TO LIFTING WEIGHTS

1. Strength of Lifting

Claims concerning the physiological or anthropometric correlates to lifting strength are varied. Whitney (1958) made it clear that in most lifting actions, the body weight, which acts as a counterbalance, must have a proportional relationship (associated, of course, with the center of gravity of the body) to the lifting strength. He showed that the most important factor which affected the isometric strength in a lifting action was the distance of the feet from the object to be lifted and that other features of the lifting procedure such as the "derrick" or "knee" action, or the type of grasp used, had only small effects on the strength exerted. Poulsen (1970) came to the conclusion that the maximum load that can be lifted correlated well with the maximum isometric strength of the back muscles; it must be noted, however, that the isometric strength of the back muscles was measured with a dynamometer that did not directly duplicate the lifting task. Recent proposals concerning "safe" weights to be lifted in a wide range of positions have been put forward (e.g., Davis and Stubbs, 1977), which are based on intra-abdominal pressures generated in the act of lifting.

2. Repetitive Lifting

In a series of studies on healthy young males and females who were trained to lift boxes, Lind and coworkers observed the following:

A. Aerobic capacity. The $\dot{V}O_2$ max for men who lifted by the cantilever (bent back) method from the floor to a bench 60 cm high (24 inches) was,

1) substantially lower when lifting boxes than on the bicycle ergometer (15% lower when lifting a box weighing 36.4 kg, or 80 lb).

2) directly related to the weight of box, from 1 kg to 36.4 kg.

3) determined, by subjective impression, by the rate at which the trunk and head could be moved for boxes weighing up to 6.8 kg (15 lb) but by fatigue in the forearm muscles when the box weighted 36.4 kg (80 lb). (Lind et al., 1979; Petrofsky and Lind, 1978).

The $\dot{V}O_2$ max of women lifting with the bent-legs method from the floor to a bench 60 cm high (24 inches) showed,

1) no differences in $\dot{V}O_2$ max for boxes weighing 15.9 kg (35 lb) and 22.7 kg (50 lb) and were not statistically different from that measured on the bicycle ergometer. The difference in pattern of response with that of the male subjects is attributable to the different method of lifting.

2) the $\dot{V}O_2$ max increased with the weight of box, from 2 kg (4.4 lb) to 22.7 kg (50 lb) (Lind et al., 1979, Williams et al., 1980).

B. Level of aerobic capacity associated with fatigue. When men lifted boxes from the floor to a bench 60 cm high (24 inches) for one hour,

1) the evidence from oxygen uptake, heart rate and arterial lactate support the view that fatigue was generated when the work rate exceeded 50% of the $\dot{V}O_2$ max for the given weight of box (i.e., at levels as low as 35% of the $\dot{V}O_2$ max established on the bicycle ergometer for these subjects).

2) there was a reduction on hand-grip isometric endurance (measured after the hour's lifting) linearly related to the weight of the box; electromyographic evidence showed more fatigue generated in the forearm than in the back muscles during lifting. (Lind et al., 1977; Petrofsky and Lind, 1978a).

When women lifted boxes by the bent leg method from the floor to a bench 50 cm high (24 inches),

1) the evidence from oxygen uptake, heart rate, and forearm electromyograms showed that fatigue occurred at approximately 50% of the $\dot{V}O_2$ max measured for the weight of box being lifted (i.e., at levels corresponding to some 40% $\dot{V}O_2$ max for bicycle ergometry at box weights up to 6.8 kg (15 lb).

2) there was a reduction of hand-grip endurance after the hour's lifting which was linearly related to the weight of box. That reduction was not as great as in the data from men. (Lind et al., 1979; Williams et al., 1980).

B. Relationship of $\dot{V}O_2$ to weight of box and frequency of lifting. For all the data available, irrespective of the origin of the lift and its vertical travel, there is

1) a linear increase in $\dot{V}O_2$ with the rate of lifting boxes of the same weight.

2) a linear increase in $\dot{V}O_2$ with the weight of box at the same rate of lifting.

3) a greater $\dot{V}O_2$, when the weight of box and the rate of lifting are constant, when the lifting is performed by the bent-leg method when compared to the cantilever method. (Aquilano, 1968; Hamilton, 1969; Brown, 1971; Snook, 1971; Lind et al., 1977; Miller, et al., 1977; Lind and Petrofsky, 1978a; Lind, et al., 1979; and Williams, et al., 1980).

C. Relationship of $\dot{V}O_2$ with point of origin and height of travel of lifting.

1) There are comparable data on $\dot{V}O_2$ from experiments in which the boxes are lifted from the floor to a height of 50 to 90 cm (20 to 35 inches) when the weight of box and the rate of lifting are constant. The variation in average VO_2 can be attributed to different sizes of box or the method of lifting.

2) The energy cost of lifting boxes from "table" height, 50 to 90 cm (20 to 35 inches) to a height of 100 to 120 cm (40 to 47 inches) is substantially lower than lifting from the floor when the weight of box and the rate of lifting are kept constant.

3) When boxes are lifted down from 60 cm (24 inches to the floor, the VO_2 is lower than when lifting upwards over the same distance.

4) Lifting and turning to place the weight at 90° to the point of origin results in the same regression equations for lifting in the sagittal plane. (Aquilano, 1968; Hamilton, 1969; Miller, et al., 1977; Petrofsky and Lind, 1978a; Snook (1978; and Lind, et al., 1979).

The results from laboratory experiments suggest that lifting exercises in industry will seldom reach or exceed the average male worker's 50% $\dot{V}O_2$ max, which is taken to be the physiological limit beyond which muscular fatigue (and its physiological sequelae) will inevitably occur. Indeed, it seems that there will be few practical situations where the average energy cost of lifting in industry is likely to exceed 35% $\dot{V}O_2$ max, a level of work which is considered by most research workers to be compatible with daily levels of work in "heavy" industries irrespective of age, sex, and other factors which are known or suspected to limit the permissible daily energy expenditure in industry.

One factor that remains to be satisfactorily defined and categorized as a limiting factor in lifting is the static isometric component and its associated physiological responses.

DETERMINATION OF WORK CAPACITY LIMITS BASED UPON ENERGY EXPENDITURE

1. Population Capacity Estimates

Adjusting for age, sex, and body weight variation in the working population Chaffin, (1972) predicted the variation in aerobic capacities illustrated in Figure 4.1. The lower 95 percent prediction intervals are also plotted.

Unfortunately, a large scale evaluation of the aerobic capacities of the American working population has not been undertaken so that values presented in this figure are only rough estimates. Cross-sectional population distributions summarized by Cumming (1967) conform to these data. A study by Rodahl and Issekutz (1962) of American policemen, however, indicates that persons having relatively sedentary jobs would have lower aerobic capacities than expected from Figure 4.1. As a result Chaffin estimated that

> "probably 80 percent or more of American men are not physically fit, as judged by their aerobic capacities being below a reasonable value of 16 Kcal/min."

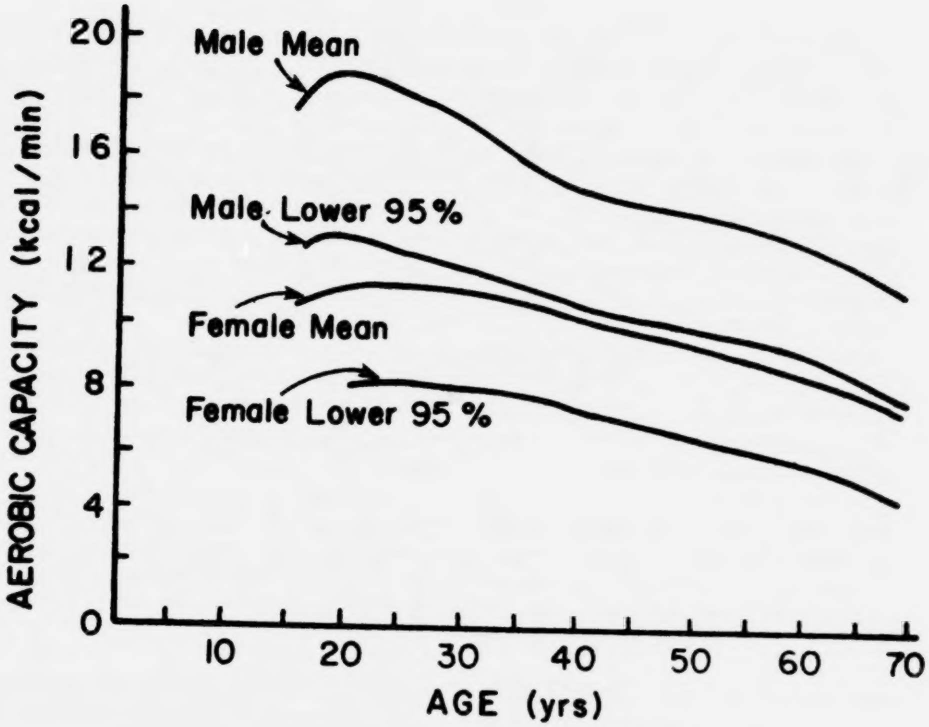


Figure 4.1: Estimated Population Aerobic Capacities for U.S. Men and Women (Chaffin, 1972).

Because the aerobic capacities in the working population vary so greatly, persons being considered for jobs requiring high metabolic demands should be specifically tested. Often aerobic capacity testing is done in industry on those persons who have a history of cardiovascular problems. In this sense it is used to determine the effectiveness of various cardiac rehabilitation programs, rather than being a tool of preventive medicine. Only through routine aerobic capacity testing in industry can objective decisions be made about what job is "too difficult for certain susceptible groups of people and for specific individuals. For the present, the recommendations provided later in this Guide are based on an assumed aerobic capacity of 15 Kcal/min. for men (cf. Robinson, 1939) and 10.5 (70% of men) for women (cf. Astrand, 1960). These limits may be too high, however, for a de-conditioned, aging workforce. Aerobic capacity testing of a broad, cross-section of the U.S. workforce is needed.

2. Eight Hour Work Duration

In terms of endurance, a controversy exists in the literature over appropriate allowances for extended continuous work.

Christensen (1955) proposed that if work is performed with an energy expenditure rate below 50 percent of a person's aerobic capacity, excessive fatigue will not occur. Astrand (1960) tested subjects with a large variation in aerobic capacities (from 11.2 to 26.0 Kcal/min.) and found that when subjects were performing at 50 percent of their aerobic capacities for eight hours, their heart rates increased to a level of 120 to 135 beats per minute. She observed that, if the aerobic capacities had not been measured (and energy expenditure rates adjusted accordingly) the heart rate in the older subjects (with limited aerobic capacities), if required to perform at the same energy expenditure rates as the younger subjects, would have incurred a heart rate increase of 30 beats/minute in the first hour of work. Thus the older subjects would have rapidly approached their predicted maximum heart rates of about 165 beats per minute.

Studies by Lehmann (1953) and Bink (1962, 1964) indicated that a work load of 5.2 Kcal/minute is the maximum energy expenditure rate that should be expected for an eight hour workday. Lehman assumed a mean age of males of 35 years, with 2500 Kcal to be available during an 8 hour day.

Legwork at levels above 5.0 Kcal/minute in well-trained individuals has been found to cause increased levels of blood lactate (Ekblom, et al., 1968). This is further evidence to indicate that the metabolic demand for oxygen within the muscles is not completely fulfilled when the task is at higher levels than 33 percent of the aerobic capacity of the person, even with highly dynamic work. Additional support for using a 33 percent value rather than the higher 50 percent of aerobic capacity is suggested by Snook and Irvine (1969). They found that when healthy industrial men were allowed to choose the amount of repeated lifting acceptable for eight hours, they chose a level that produced a heart rate averaging 112 beats per minute, which would be equivalent to about 5.0 Kcal/minute of energy expenditure.

A more recent industrial study by Rodgers (1976) supported a lower (33 percent) capacity in concluding:

> "We have observed that most people will select a level of effort that keeps them within the 33% of maximum capacity guideline and will also integrate other factors such as:
>
> - the biomechanical aspects of materials to be handled--grasping characteristics, size, etc.
> - environmental characteristics of the workplace--heat, hours of work, chemical agents, pacing, etc.
> - the individual's physical fitness level

- the individual's skill level--training and experience on the job
- the individual's activities outside of work--second job, housework, etc."

In industrial work there is the additional problem of static muscular effort (posture maintenance and holding of worklaods) which reduces blood flow. This would indicate that aerobic capacities for this type of work would in general be lower compared to the dynamic capacities assumed in the above studies (Lind, et al., 1979; Williams, et al., 1980).

For the purposes of this Guide, the lower (33 percent of aerobic capacity) will be assumed for 8 hour work duration.

3. Working Time Prediction

With reference to a normal, healthy, 35-year-old working man, three limitations in physical work capacity as a function of working time were proposed by Bink (1962) and Bonjer (1962):

1) An upper energy work limit of 16 Kcal/minute for four minutes (i.e., aerobic capacity)
2) an eight-hour continuous work limit of 5.2 Kcal/minute, which is 33 percent of (1).
3) a 24-hour performance limit of 2.85 Kcal/minute (based on dietary considerations, (V.V.V. 1958).

The resulting logarithmic relationship of working time to work capacity is illustrated in Figure 4.2. The use of such a logarithmic relationship of the working time and the average work capacity has also been discussed by Bonjer (1971) and Moores (1970).

An example application of the working time prediction concept is illustrated with a coal mining job consisting of the following productive activities (Garry, 1952).

Activity	% of Time	Average Metabolic Rate (Kcal/min.)	Weighted Metabolic Rate (Kcal/min.)
Loading	42%	6.3	2.64
Standing	7%	1.8	0.12
Walking	23%	6.7	1.54
Hewing	4%	6.7	0.27
Timbering	24%	5.7	1.37

Predicted Average Metabolic Rate = 5.94 Kcal/min.

Assuming that a physically fit 35-year-old man (16 Kcal capacity) should be capable of working this job, then it is predicted (from Figure 4.2) that the working time will need to be reduced from a 480 minute day to a 340 minute day, with 140 minutes of rest.

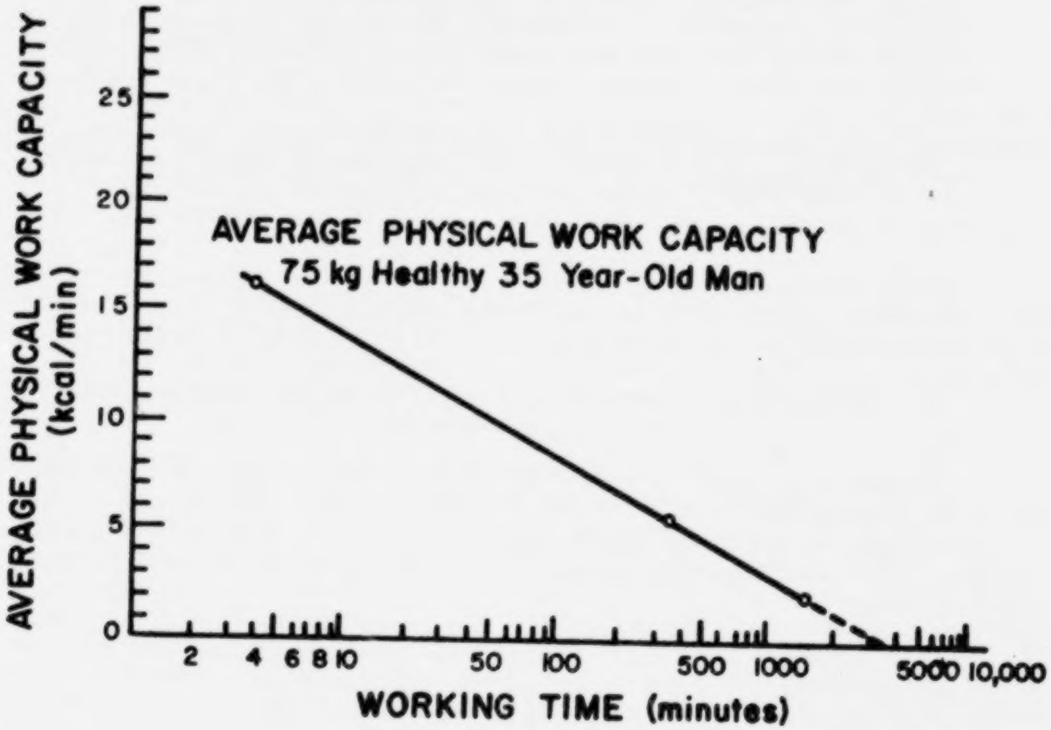


Figure 4.2: Physical Work Capacity and Working Time (Bink, 1962 and Bonjer, 1962).

4. Estimating Task Energy Requirements

Given the ability to assess an individual's metabolic work capacity, adjusted for work duration, the question remains: "How can this be related to a job?" At present, the three commonly used methods for determining the metabolic demands of a particular job are:

1) measurement of oxygen consumption on incumbent workers
2) estimating using tabulated survey values
3) estimating using mathematical models.

On-the-job measurement of oxygen utilization is the most straight-forward method for determining the metabolic energy requirements of a particular person on a particular job. However, on-the-job measurement of oxygen utilization is sometimes difficult due to interference of measuring equipment with the normal work methods. Handling methods, work operations, weight and size of working material and the particular workers may be continually changing (Aberg, et al., 1968), and individual oxygen uptake measurements made today may not be valid later.

On the other hand, extensive tables of metabolic energy expenditure estimates for more than 1000 different activities are available in the literature. Table 4.1 illustrates the average energy costs for a small set of selected activities (Durnin and Passmore, 1967). Such studies provide estimates of the metabolic energy expended by the "average" person who is performing complex manual activities under different working conditions such as unloading coal cars, handling boxes, stapling, loading corrugated cartons (Davis, et al., 1969), working in a hot environment, construction work, etc.

Table values, however, provide only a rough approximation of the metabolic cost of a given job. Such values are specific to particular work situations employed at the time of measurement and do not (for the most part) reflect the variable effects of important personal and task parameters such as body weight, postures, object weight, object size, travel distance, etc. Without more detailed task descriptions it is difficult to interpolate or extrapolate such values.

A third group of studies relate metabolic energy expended by a person to the physical measures of the activity. Primarily through regression and analysis of variance models, empirical relationships between metabolic energy expenditure rates and one or more of the physical parameters of the job have been modelled (Frederik, 1959); Cotes and Meade, 1960; Grimby and Soderholm, 1962; Garg, 1976; Aquilano, 1968; Aberg, et al., 1968; Hamilton and Chase, 1969; Soule and Goldman, 1969; Givoni and Goldman, 1971; Kamon and Belding, 1971; Snook, 1971; Chaffin, 1972; Van Der Walt and Wyndham, 1973; Garg, et al., 1978). In general, it is noted that minor changes in the physical parameters that are commonly used to describe the manual activity result in significant changes in metabolic energy expenditure predictions as will be illustrated in the following section.

5. Variables Affecting Metabolic Rate

In order to develop a predictive model of metabolic rate for lifting a number of variables must be considered. Table 4.2

Table 4.1: Average energy cost while performing selected activities. Values apply for 70-kg (154-pound) man. For most activities adjustment for cost is proportional to body weight. (Durnin and Passmore, 1967)

Body Position and Activity	Total Energy Cost Typical	Kcal/min Range
Heavy activity at fast to maximum pace		10.0-20.0
Jogging, level, 4.5 mph	7.5	
Lifting, 20 kg, 10 cycles per min.		
floor to waist	8.2	
floor to shoulder	10.8	
Reclining, at rest	1.3	
Running, level, 7.5 mph	12.7	
Shovelling, 18 lb. load 1 yd. with 1-yd. lift, 10 times per min.	8.0	
Sitting, at ease		
light hand work (writing, typing)	1.7	1.6-1.8
moderate hand and arm work (drafting, light drill press, light assembly, tailoring)		
light arm and leg work (driving car on open road, machine sewing)	2.8	2.5-3.2
heavy hand and arm work (nailing, shaping stones, filing)	3.5	3.0-4.0
moderate arm and leg work (local driving of truck or bus)	3.6	3.0-4.0
Standing, at ease	1.9	
moderate arm and trunk work (nailing, filing, ironing)	3.7	3.0-4.0
heavy arm and trunk work (hand sewing, chiselling)	6.0	4.0-8.0
Walking, casual (foreman, lecturing)	3.0	2.5-3.5
moderate arm work (sweeping, stockroom work)	4.5	4.0-5.0
carrying heavy loads or with heavy arm movements (carrying suitcases, scything, hand-mowing lawn)	7.0	6.0-8.0
transferring 35 lb. sheet materials 2 yds. at trunk level, 3 times per min.	3.7	
pushing wheelbarrow on level with 220 lb. load	5.5	5.0-6.0
level, 2 mph	3.2	
3 mph	4.0	
4 mph	5.9	

shows the major tasks and personal factors known to affect metabolic energy expenditure rates. A brief description of the effects of each factor follows.

Table 4.2: Major factors affecting metabolic energy expenditure rate.

Worker Variables	Task Variables
1. Gender	4. Load
2. Body Weight	5. Frequency of loading of body
3. Lifting Techniques	6. Vertical travel distance
	7. Vertical origin of lift
	8. Temperature and humidity

The effects of age and body weight have been discussed in the section on dynamic exercise (p. 41).

Other factors affecting the metabolic rate include:

1. Body Posture (or Technique). The body posture used to lift a load may affect the metabolic cost of the job considerably. The following are some of the reasons:
    1. Different body postures affect the loading of different muscle groups and different muscle groups have different metabolic efficiencies.
    2. Body posture affects the muscle moment arm and length of the muscle. Metabolic efficiency is related to muscle tension which is a function of length of the muscle and speed of shortening (Hill, 1938).

3. Squat lifting requires more work to lift the body itself than stoop lifting and thus involves a higher metabolic cost.

Figures 4.3 and 4.4 illustrate the importance of lift technique on metabolic rate. Brown (1971) demonstrated that free style lifting is least fatiguing compared to stooping or squatting as shown in Figure 4.3. Garg and Saxena (1979) found similar differences, expecially with frequent low level lifting as shown in Figure 4.4. (It is important to note that the variables plotted are quite different in these two figures).

2. Weight of the Load. In repetitive lifting, mechanical work per minute can be written as:

Mechanical Work = Load x Frequency x Distance of Vertical Lift

Therefore, the heavier the load to be lifted, the greater the mechanical work performed and subsequently the greater energy expenditure. Frederik, 1959; Snook, 1965; Aquilano, 1968; Hamilton, 1969; Brown, 1971; Lind, et al., 1977; and Garg, et al., 1978, have each reported that an increase in load to be lifted results in an increase in metabolic energy expenditure rate. Most studies agree that a linear relation between object weight and metabolic rate is reasonable for most lifting tasks.

3. Frequency of Lifting. Frequency is defined as the number of lifts per minute. The mechanical work done by the musculoskeletal system is also directly proportional to frequency (as noted above). If all other factors such as load, range and distance of vertical lift, speed of lift, technique, etc., are held constant, the metabolic energy expenditure rate should be directly proportional to the pace of lifting.

The effect of pace on energy expenditure has been studied by Anuilane, 1968; Hamilton, 1969; Chaffin, 1972; Snook, 1965; Garg, 1976; and Lind, et al., 1977. Figures 4.5 and 4.6 illustrate relationships between weight, lifting frequency and metabolic rate observed by Hamilton (1969 and Aquilano (1968). Thus the relationship between work pace and metabolic energy expenditure appears to be linear.

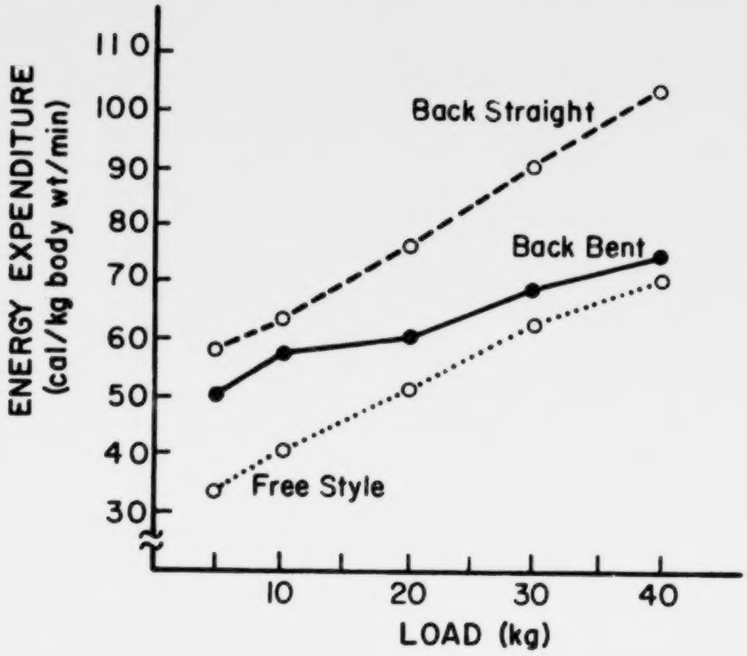


Figure 4.3: Metabolic Rate for Different Postures (Brown, 1971).

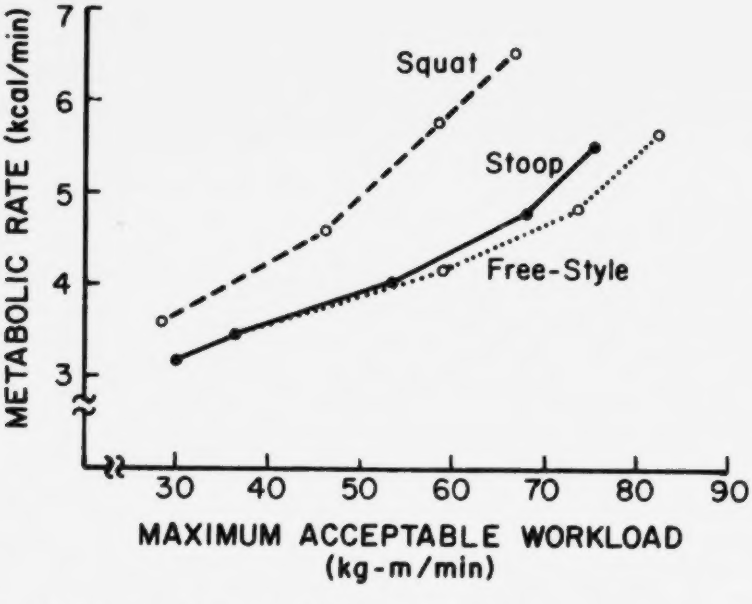


Figure 4.4: Effect of Technique and Workload on Metabolic Rate (Garg and Saxena, 1979).

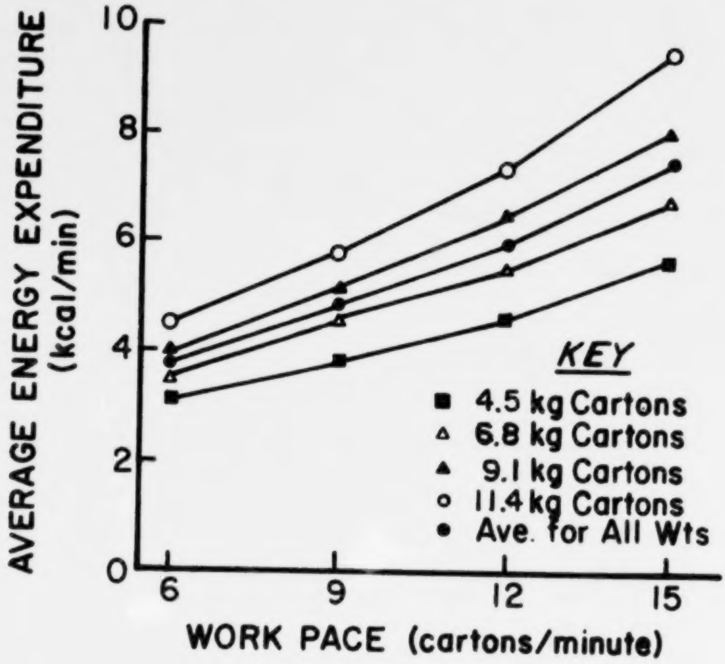
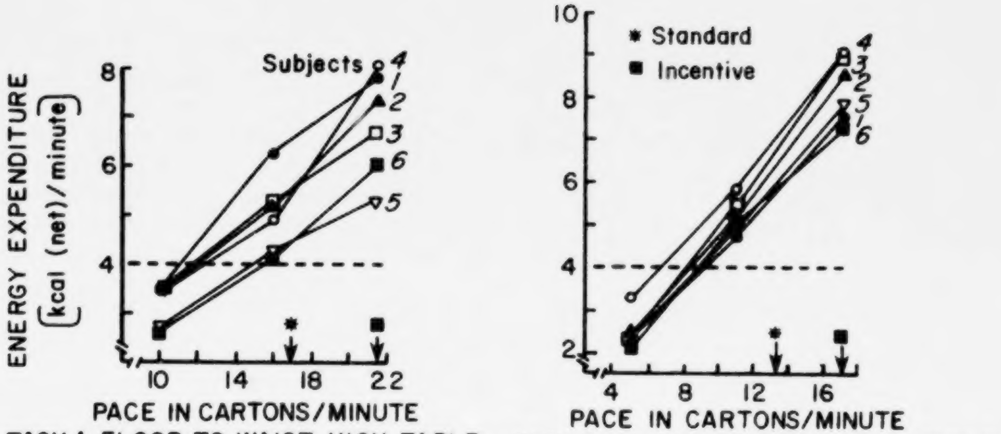


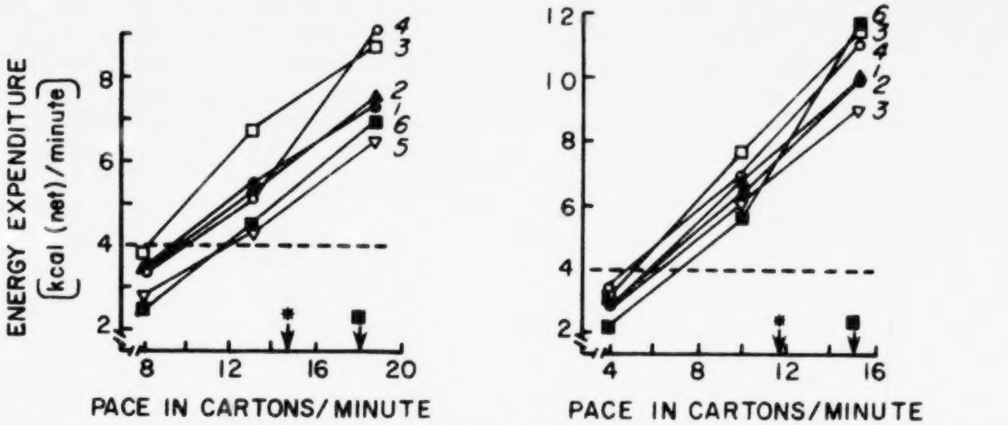
Figure 4.5: Energy Expenditure versus Work Pace (Hamilton, 1969).

4. Vertical Travel Distance of Lift. Since mechanical work is also directly proportional to vertical travel, metabolic energy expenditure should increase with an increase in vertical distance of lift. The results of Aquilano (1968) shown in Figure 4.6 also illustrate this point. When an 11 kg load was lifted from the floor to waist height (92 cm) and head height (168 cm) at a pace of 11 and 10 lifts per minute respectively, the corresponding energy expenditures were 5.21 and 6.58 Kcal/min. The exact relation between metabolic rate and vertical travel distance in this case depends on body posture. Tasks which require raising and lowering the body as well as the load affect efficiency and the total weight moved, consequently the metabolic cost of lifting.



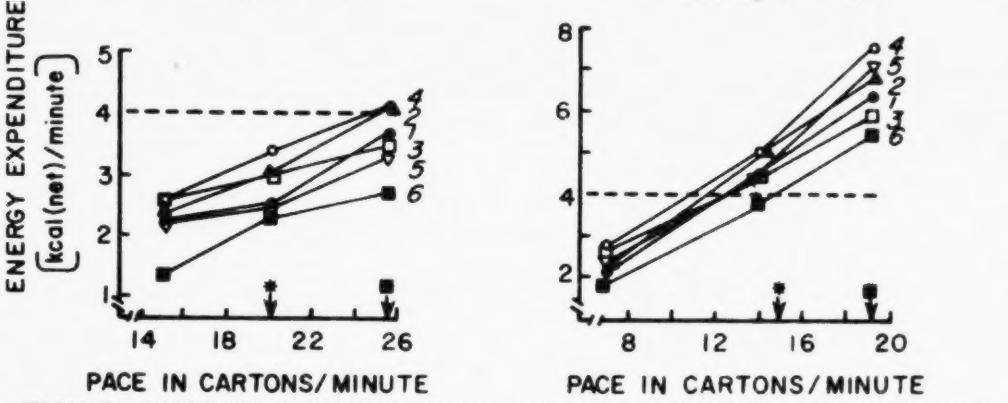
TASK 1-FLOOR TO WAIST-HIGH TABLE 4.5 kg CARTON

TASK 2-FLOOR TO WAIST-HIGH TABLE 11.4 kg CARTON



TASK 3-FLOOR TO HEAD-HIGH TABLE 4.5 kg CARTON

TASK 4-FLOOR TO HEAD-HIGH TABLE 11.4 kg CARTON



TASK 5- WAIST-HIGH TO HEAD-HIGH TABLE 4.5 kg CARTON

TASK 6-WAIST-HIGH TO HEAD-HIGH TABLE 11.4 kg CARTON

Figure 4.6: Effect of Pace on Metabolic Rate (Aquilano, 1968).

5. Vertical Location. Not only is the net vertical distance of the lift important but also the absolute vertical heights of the beginning and end point of the lift. Lifting the same net vertical distance from two different vertical heights, may result in assuming different body postures and varying amounts of movement of the center of gravity of the body. For example, consider the following two tasks (from Garg, 1976):

   Task A - Lifting 4.5 kg from a vertical height of 91 cm to a vertical height of 168 cm at a pace of 25 lifts per minute.

   Task B - Lifting 4.5 kg from the floor to a vertical height of 91 cm at a pace of 21 lifts per minute.

   In these two cases, the total mechanical work is practically the same (i.e., 86.6 and 86 kg-m). The average male energy requirements for the two tasks were 3.56 and 6.77 Kcal/minute respectively (Aquilano, 1968), even though the Task A was performed at a higher pace as shown in Figure 4.6 (Tasks 5 and 1 respectively). Here again, vertical body travel is a critical factor in estimating metabolic rate. Frederick (1959) suggested that the best area for manual lifting is between 100 and 150 cm from floor level for a standing man of average height. The physiological efficiencies (expressed in Kcal/unit of work) for four different vertical ranges of lift as given by Frederik (1959) are illustrated in Figure 4.7.

6. Temperature and Humidity. As previously mentioned, metabolic energy expenditure encompasses two forms of energy. One is mechanical energy, which is the basis of the motor performance capability of man, and the other is heat. The proportion of total energy which is converted to mechanical energy varies from zero in static work to about 30 percent for walking (Grandjean, 1969). This Guide assumes an ambient environment of 70-80°F and 40-50% humidity. Possible controls for heat stress are discussed in Chapter 7.

MODELING TASK AND PERSONAL VARIABLES

Each of the task and personal variables described in the previous section were combined into one predictive model for lifting in a study of Garg, et al., (1978). According to this model the metabolic rate for any task ($\dot{E}_T$) consists of two parts--the metabolic rate necessary to maintain posture $\dot{E}_P$ and the energy required to lift (ΔE) in the following form:

$$\dot{E}_T = \dot{E}_P + F(\Delta E)$$

where F is the frequency of lifting. The net metabolic cost of each lift (ΔE) is composed of two parts, the energy necessary to move the body and the energy necessary to move the load. Depending on the posture and vertical location:

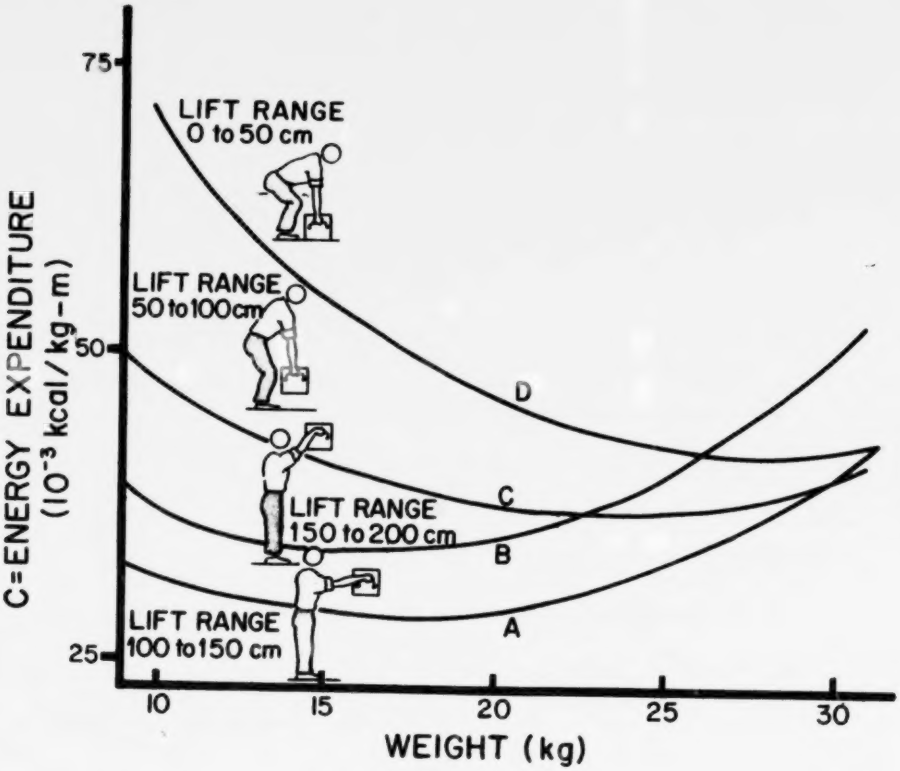


Figure 4.7 Energy Efficiency with Weight and Range of Lifting (Frederik, 1959).

For Arm Lifting (Kcal/lift):

$$\Delta E = 10^{-2}).062 \text{ BW } (F_v - .81) + (3.1L - .52 \text{ S x L})(V_2 - V_1))$$

$$\text{for } .81 \leq V_1 < V_2$$

For Stoop Lifting (Kcal/lift):

$$\Delta E = 10^{-2} (0.325 \text{ BW } (0.81 - V_1) + (1.41L + 0.76 \text{ S x L})$$

$$(V_2 - V_1)) \text{ for } V_1 < V_2 < 0.81$$

For Squat Lifting (Kcal/lift):

$$\Delta E = 10^{2} (0.514 \text{ BW } (0.81 - V_1) + (2.19L + 0.62 \text{ S x L})$$

$$(V_1 < V_2 < 0.81$$

where:

BW = Body weight (kg)

V_1 = Vertical height from floor (m); starting point for lift and end point for lower

V_2 = Vertical height from floor (m); end point for lift and starting point for lower

L = Weight of the load (kg)

S = Gender (1 for males; 0 for females)

$\dot{E}_P$ = .924 VW if standing erect

= .028 if standing in bent position (Aberg, 1968)

Application of the model to predict metabolic rates on 48 different industrial jobs showed a simple correlation of .95 with a standard error of 10.2% (Garg, et al., 1978). Simplifying the above equations based on an average male body weight (BW = 77 kg), lifting from the floor ($V_1 = 0$) to bench height ($V_2 = .81$) and assuming a desired average metabolic rate ($\dot{E}_T$) of 5.2 Kcal/min. the relationships between load, frequency, and body posture can be estimated, in untrained subjects, illustrated as in Figure 4.8. This figure demonstrates the cost associated with moving the body from a squat versus stoop posture. This may be one of the reasons why workers often employ the stoop posture (minimizing energy expenditure) for a fixed work output.

The relationship between load and frequency is illustrated in Figure 4.9. This study (Snook, 1971) demonstrated the effect of work load (load x frequency x distance of lift) on metabolic rate for different loads based on 30 male workers. For a fixed work capacity criterion (such as 5.0 Kcal/min) it is apparent that a greater amount of work can be accomplished if heavier loads are lifted at slower paces.

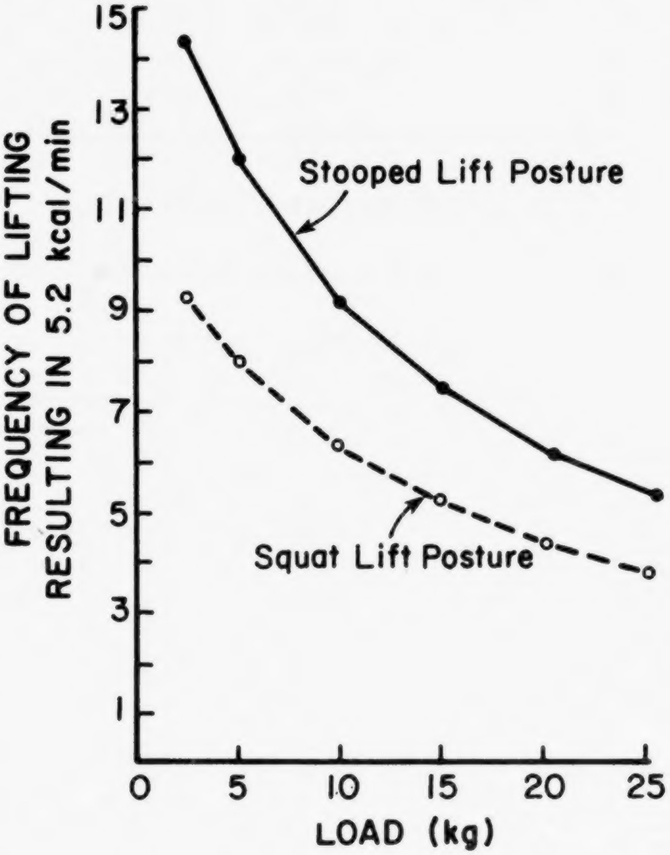


Figure 4.8: Estimated Maximum Frequency of Lift with Two Postures (Adapted from Garg and Herrin, 1979).

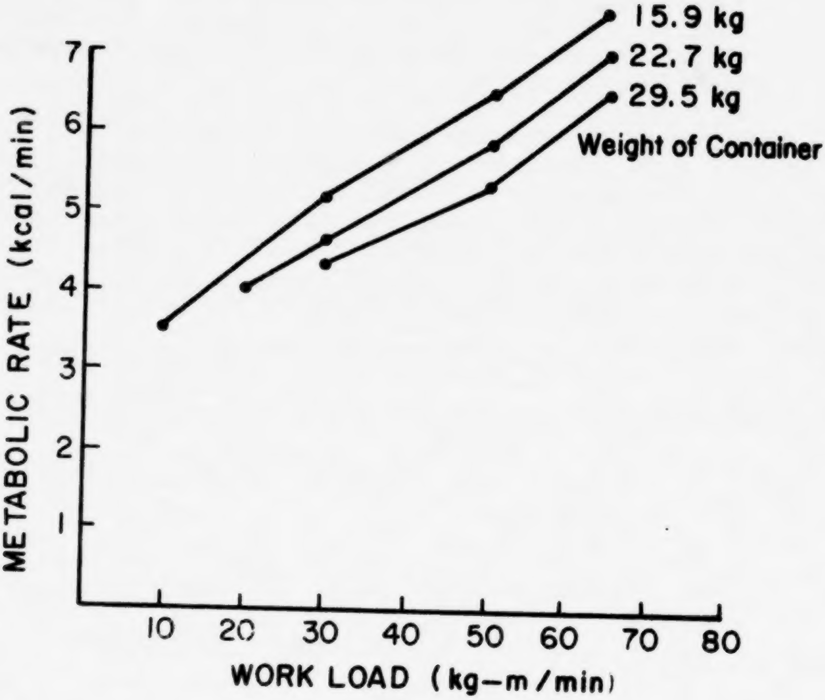


Figure 4.9: Effect of Workload on Metabolic Rate (Snook, 1971).

PHYSIOLOGICAL DESIGN CRITERIA

Based on the preceding discussion of the metabolic costs associated with repetitive work it is recommended that:

1. For occasional lifting (for one hour or less) metabolic energy expenditure rates should not exceed 9 Kcal/min for physically fit males or 6.5 Kcal/min for physically fit females (see Figure 4.10). This is based on industrial population aerobic capacity estimates discussed earlier in this chapter adjusted for working time. (It does not, however, take into account, Lind's observations that the VO_2 max Kcal/min values for men and 10.5 Kcal/min values for women).

2. Likewise, continuous (8 hour) limits should not exceed 33% of aerobic capacity or 5.0 Kcal/min and 3.5 Kcal/min respectively. These guideline limits do not reflect the increased metabolic rates which would be associated with overweight or deconditioned workforces.

3. Personal attributes of age, gender, body weight, etc. are insufficient to accurately predict work capacity for any particular individual, although such data are sufficient for making predictions of group averages.

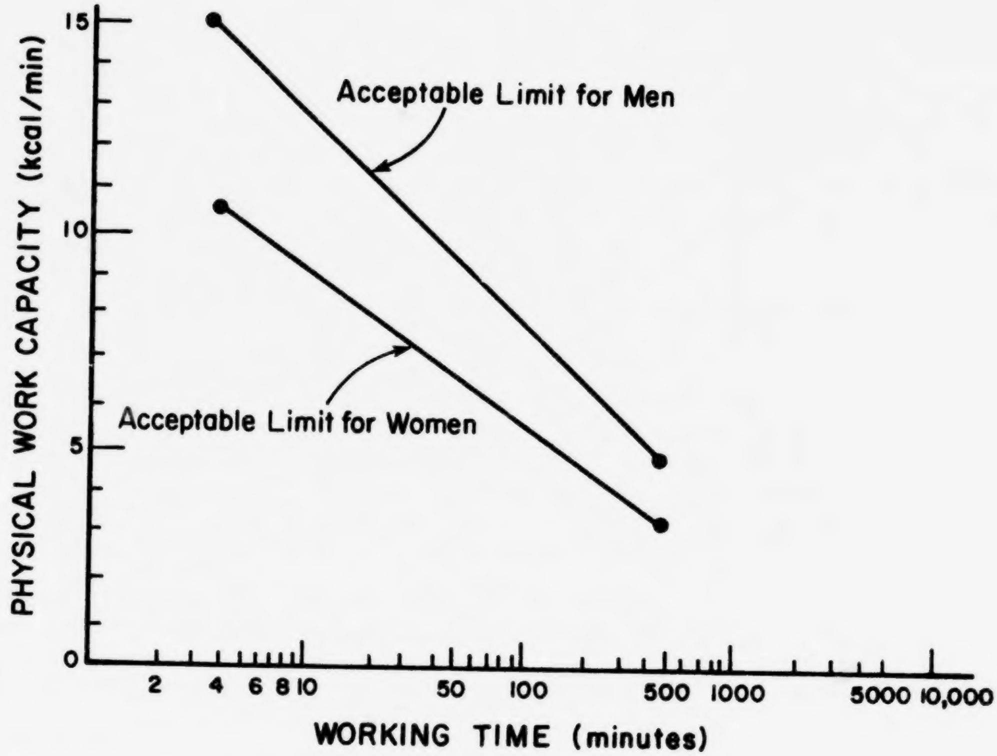


Figure 4.10: Recommend Maximum Capacities for Continuous Work.

4. The primary task variables which influence metabolic rate during lifting are

   A) load handled, L
   B) vertical location at beginning of lift, V (and consequently posture)
   C) vertical travel distance, D
   D) frequency of lift, F.

The guideline recommendations summarized in Chapter 8 combine the above criteria with the biomechanical criteria of the preceding chapter and the psychophysical criteria of the next chapter. Estimates of the metabolic rates for the various working conditions described in Chapter 8 are provided in Appendix A. These estimates are based on the model of Garg, et al., (1978) assuming an average male body weight of 77 kg for the upper limit and average female body weight of 62 kg for the lower limit.

CHAPTER 5

BASIS FOR GUIDE: PSYCHOPHYSICAL APPROACH

A minimal requirement for performing any manual materials handling task is sufficient strength to exert the required force. Strength in this context is defined as the maximum voluntary force a person is willing to exert in a single attempt. Endurance (capacity) is the force a person is willing to repeatedly exert for an extended period of time without "feeling fatigued".

In this chapter, human strength will be expressed in psychophysical terms. Unlike the biological concepts of fatigue and tissue tolerance; psychophysics is concerned with human acceptance of pain or discomfort during an exertion under normal conditions.

PSYCHOPHYSICS

Psychophysics is a very old branch of psychology that is concerned with the relationship between human sensations and their physical stimuli; very rarely is this a one-to-one relationship. According to modern psychophysical theory (Stevens, 1960), the strength of a sensation (S) is directly related to the intensity of its physical stimulus (I) by means of a power function: $S = kI^n$. The constant (k) is a function of the particular units of measurement that are used. When plotted on log-log coordinates, a power function is represented by a straight line, with the exponent (n) being equal to the slope of the line. Exponents have been experimentally determined for many types of stimuli, for example, 3.5 for electric shock, 1.3 for taste (salt), and 0.6 for loudness (binaural). Of interest here is the perception of muscular effort and force, both of which have been found to obey the power law, and both with an exponent of approximately 1.6 (Borg, 1962; Eisler, 1962). Stevens and Cain (1970) found that the exponent for duration of hand grip is about half the exponent for force of hand grip.

Psychophysics has been applied to practical problems in many areas. For example, the scales of effective temperature, loudness, and brightness were developed with psychophysical methodology (Houghton and Yagloglou, 1923; Stevens, 1956, 1960). Psychophysics has also been used by Borg (1962, 1973) in developing ratings of perceived exertion (RPE); by the U.S. Air Force in studies of lifting (Emanuel, et al., 1956; Switzer, 1962); by the U.S. Army in studies of treadmill walking (Evans, 1961, 1962); and in the development of effort scales (Caldwell and Smith, 1967; Caldwell and Grossman, 1973).

STATIC STRENGTH

The usefulness of any test of human performance is inherently limited by the reliability and repeatability of the measurement technique. Strength is no exception. It is susceptible to many influences which can affect the outcome of the measurement. Following a review of the literature by Kroemer and Howard (1970), it was recognized that there was little uniformity in either the techniques used in assessing strength or in the statistical methods used to report the results of studies. Due to the lack of consensus on methodology, an ad hoc committee of experts first held a series of meetings in 1972 for the purpose of proposing a strength testing standard (Caldwell, et al., 1974). The recommendations of this group were later adopted as an "Ergonomics Guide for the Assessment of Human Static Strength" by the American Industrial Hygiene Association (Chaffin, 1975). This guide describes the use of static tests for the measurement of human strength.

Static strength is defined as:

> "...the maximal force muscles can exert isometrically in a single voluntary effort." (Roebuck, Kroemer, and Thompson, 1975).

There are several advantages in using this technique of strength assessment.

1. The technique is relatively simple. The subject is asked to assume a particular body posture and to exert a force against a stable resistance. As a result, the position of the subject's joints are under the control of the experimenter and only one measurement is required, namely the magnitude of the exertion. On the other hand, dynamic strength tests involve body motion. The positions of the subject's joints are no longer controlled and, therefore, should be continuously monitored. Furthermore, the velocity and acceleration of various body members need to be measured. Instead of recording and analyzing a single result, many data points must be considered in the dynamic analysis of strength (Kroemer and Howard, 1970; Caldwell, et al., 1974).

2. Subjects are at minimal risk of injuring themselves during this type of test since the exertion is isometric and completely voluntary. They are requested to slowly increase their exertions, and to stop if any abnormal discomfort is felt.

3. The measurement is repeatable with a high degree of reliability, (test-retest coefficient of variations on the order of 14 percent are reported by Chaffin, et al., 1977).

Although repeated strength tests on a particular muscle group are highly reliable, the strengths of different muscles, even within subjects, are only weakly correlated (Thordsen, et al., 1972; Laubach, et al., 1972). In these studies, 51 subjects were asked to perform maximal isometric exertions in 44 different tests. Of the 768 simple correlations among the 44 measures taken, only 13 had correlation coefficients of .71 or higher (i.e., could explain at least 50 percent of the variance). This finding indicates that when it is necessary to determine a person's ability to perform a particular job element, it is often more accurate to simulate the job's activity in a strength test, rather than trying to predict job strength from standardized tests.

A number of studies by Asmussen and Heeboll-Nielsen (1961), Backlund and Nordgren (1968), Chaffin (1974), Kroemer (1969), Laubach and McConville (1969), Snook, Irvine and Bass (1970), Snook and Ciriello (1974), Troup and Chapman (1969), Nordgren (1972) report strength capabilities of various populations. Laubach (1976) summarized each of these studies in a review of the literature. He concluded that average female strength ranges between 35 and 84 percent of average male strength, depending on the nature of the test and specific muscles involved. Averaging the results of all nine studies, women were found to demonstrate only about 64 percent of the strength men demonstrate. Mean values however do not reflect the variability of strength within each gender. When this is accounted for, the problem becomes more complex as discussed below.

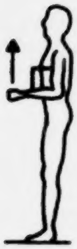
Recently, Keyserling, et al., (1978) summarized the isometric strength of 1,239 workers in rubber, aluminum, steel and electronic component industries as shown in Table 5.1. Attempts to predict these six isometric strengths based on individual worker height (S), body weight (W), age (A), and gender (G) revealed that anthropologic measures are not good predictors of strength. Calculated coefficients of determination (R^2) indicate that these variables rarely explain more than one-third of the population variance as shown in Table 5.2.

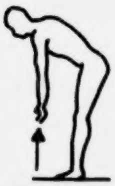
Gender, however, is an important factor in predicting strength, with females being weaker than males. (Note the negative regression coefficients involving gender.) Also, taller, heavier workers are stronger (positive regression coefficients for the S x W interaction) than their counterparts and body weight is detrimental to strength with increasing age.

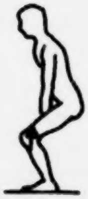
An important point with this table is that unexplained variability between (among) and within (test-retest) particular individuals was quite large (ranging from an average standard deviation of 6.4 kg for high far lifting to 29.0 kg for leg strength). Consequently, it would be imprudent to use these anthropologic variables alone to predict how any particular individual would fare on a particular strength demanding task.

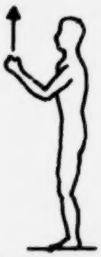
Table 5.1: Maximal voluntary isometric strength (kilograms)

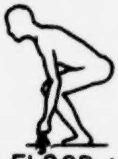
		MALES							RETEST		FEMALES				
				POPULATION %TILE							POPULATION %TILE				
TEST	ASSUMED DISTRIBUTION	SAMPLE SIZE	COEFF. OF VARIATION	10	25	50	75	90	SAMPLE SIZE	COEFF. OF VARIATION	10	25	50	75	90
1. Arm Lift	Normal	1052	.07	23	31	39	48	56	187	.08	9	15	22	28	34
2. Torso Lift	Log Normal	1052	.09	26	34	45	60	77	187	.10	13	17	24	33	44
3. Leg Lift	Normal	638	---	49	69	91	114	134	133	--	5	27	40	53	64
4. High Far Lift	Log Normal	309	.09	16	19	23	28	34	35	12	9	11	13	16	19
5. Floor Lift	Normal	309	.08	59	74	91	108	123	35	.08	32	44	56	69	80
6. High Near Lift	Normal	309	.08	35	44	55	66	76	35	[illegible]	16	[illegible]	29	36	42


(1) ARM LIFT
90°


(2) TORSO LIFT
V=38 cm H=38 cm


(3) LEG LIFT
V=38 cm H=0 cm


(4) HIGH FAR LIFT
V=152 cm H=51 cm


(5) FLOOR LIFT
V=15 cm H=25 cm

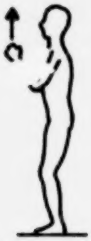

(6) HIGH NEAR LIFT
V=152 cm H=25 cm

Table 5.2: Prediction equations using anthropometry (Keyserling, et al., 1978)

STRENGTH	REGRESSION EQUATION	R^2	STD. ERROR
Arm Lift	Y = 23.8 - 13.2G + .00162SxW - .00303WxA	.294	11.5
Torso Lift	Y = 11.4 - 14.7G + .00309SxW + .00263SxA - .00844WxA	.204	19.4
Leg Lift	Y = 61.5 - 41.2G + .00422SxW - .0109WxA	.379	29.0
High Far Lift	Y [illegible] 6.2[illegible] + .00117SxW [illegible] .000571SxWxG	.302	6.44
Floor Lift	[illegible] 50.9 - 69.8G + [illegible]SxW - .0000[illegible]02SxWxA + .00977SxAxG	.246	23.1
High Near Lift	[illegible] 510S [illegible] 6[illegible]G - .0000189SxWxA	.307	14.5

S [illegible] height [illegible] m
W [illegible] body [illegible] kg
A = age (years)
G = gender (0=male, 1=female)

A similar study by Kamon and Goldfuss (1978) of 457 male and 137 female industrial workers produced comparable results as illustrated in Figure 5.1. The back extension measures reported here are not directly comparable to the results of Keyserling, et al., (1978) due to methodological differences. The elbow flexion data are comparable to Tables 5.1 and 5.2. In both studies, unexplained differences between individuals were foughly 1/3 of the mean values.

STATIC STRENGTH MODELS

Very few predictive models of human strength are available in the literature. Most models are regression models which are very poor in terms of interpolation and extrapolation from experimental data. The primary reason for the lack of models is the complexity of the human body.

A computerized, 3-dimensional isometric strength model is reported by Garg and Chaffin (1975). This model is based on a mechanical analog of the human body. This analog treats the body segments as a set of links with masses distributed as dictated from many past population surveys depicted spatially in Figure 5.2.

Essentially, this model develops resultant torque estimates at each joint center for specified external forces acting on the body. These are then compared to the inputted reactive volitional torques that can be achieved at each joint (i.e., to the muscle

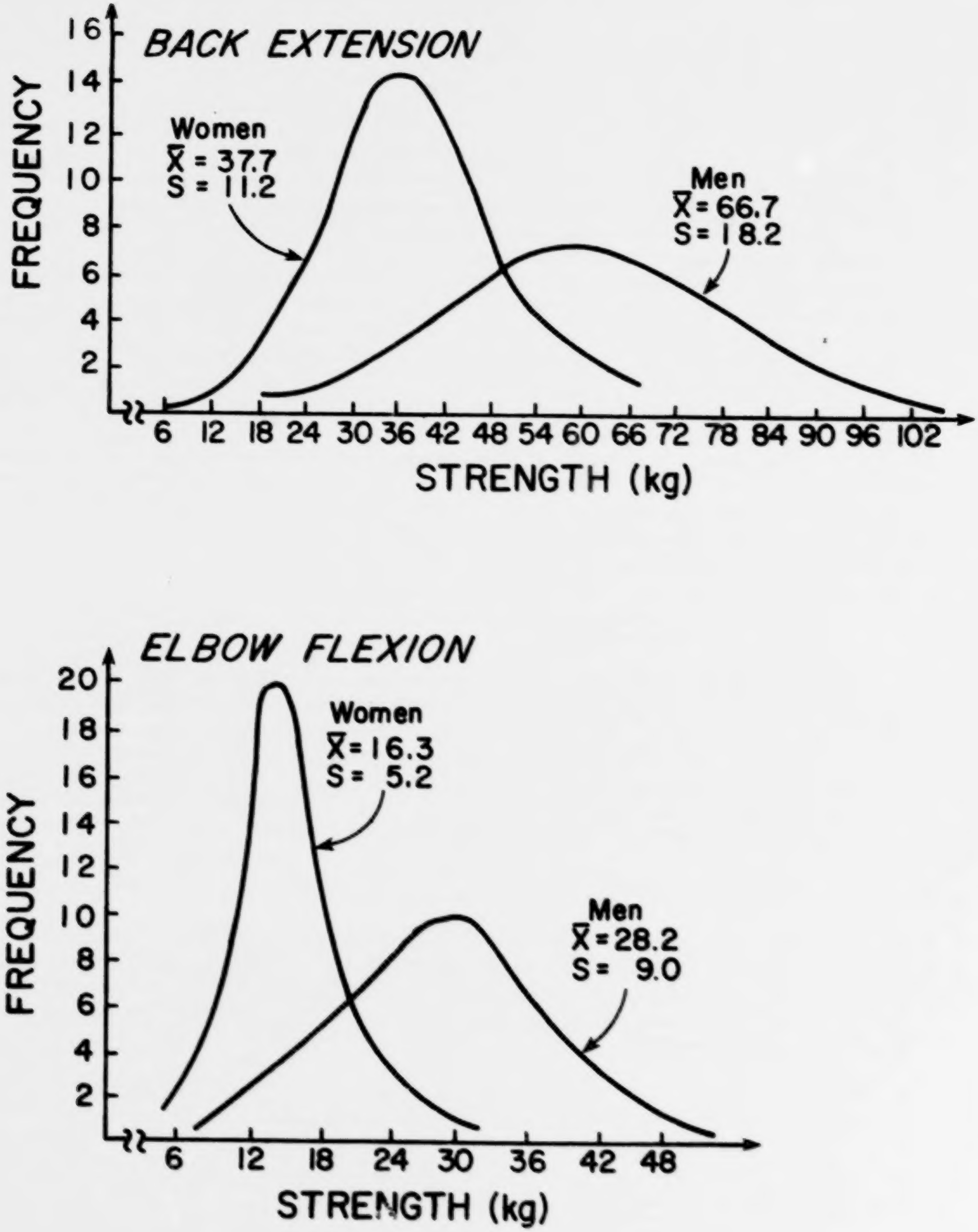


Figure 5.1: Strength Differences between Male and Female Industrial Workers (Kamon and Goldfuss, 1978).

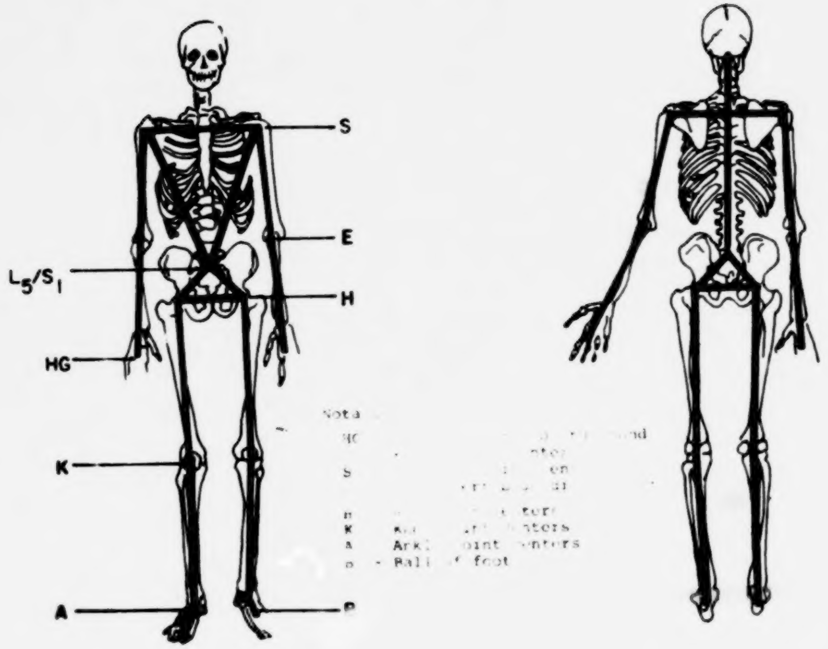


Figure 5.2: Linkage representation (Garg and Chaffin, 1975)

group strengths). Figure 5.3 depicts the body angles used to describe the posture of a person for modeling. For each angle there are at least two opposing muscle strengths that must be inputted to the model to act as the limiting reactive voluntary torques at each joint. These inputted muscle strengths need to either be measured, or population distribution strengths can be assumed. The model then allows the manipulation of the external forces and postures of interest to determine the maximum hand forces that can be produced by a designated population without having a joint resultant torque exceed a given joint reactive torque strength. Thus, the model can be thought of as depicting the static muscular capability of a person in any posture and load combination described.

Two other human limitations are recognized by the model for strength prediction. One is the body balance capability. As an example it is possible when standing that the external forces on the body can cause the line of gravity of the total person/load system center of gravity to be outside the area bounded by the feet, and hence the person will fall over if a rapid postural correction is not made. This loss of static equilibrium is assessed for any posture and force combination inputted to the model,

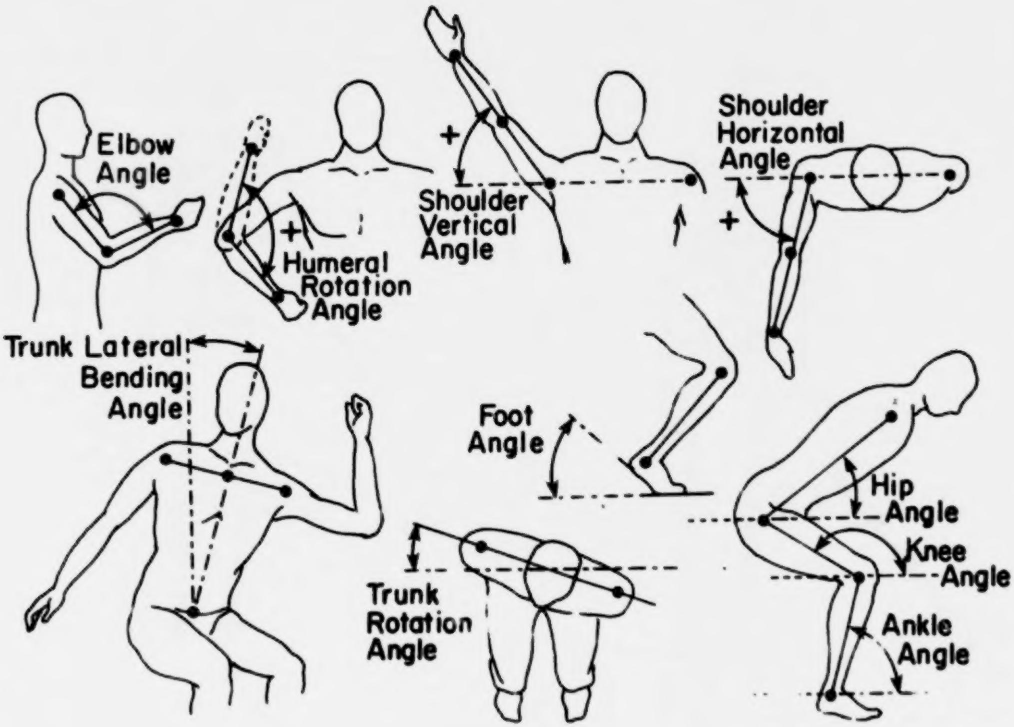

Elbow Angle
Humeral Rotation Angle
+
Shoulder Vertical Angle
+
Shoulder Horizontal Angle
+
Trunk Lateral Bending Angle
Foot Angle
Hip Angle
Knee Angle
Ankle Angle
Trunk Rotation Angle

Figure 5.3: Body Angles Used to Depict Posture (Garg and Chaffin, 1975).

and hence the user can easily determine when balance is critical to task performance.

The final constraint in the model is based on evidence that lumbar compression forces may limit a person's volitional capability as discussed in Chapter 3. Thus, an assessment similar to the Morris, Lucas and Bresler Model of low-back compression has been included in the strength model, with acceptable compression limits being selected by the user.

Figure 5.4 illustrates the strength capabilities of a strong 2.5 percentile male (97.5% of males have a lower strength capability) predicted with a two-dimensional form of the model (Chaffin, 1974). Similar force contours could be defined for other population percentiles and anthropometric characteristics (i.e., age, gender, body weight, stature, etc.). These are summarized at the end of this chapter.

In summary, this model produces three key pieces of information. First, it allows the rank ordering of the gross strength requirements of the various tasks involved in a job. Second, it identifies

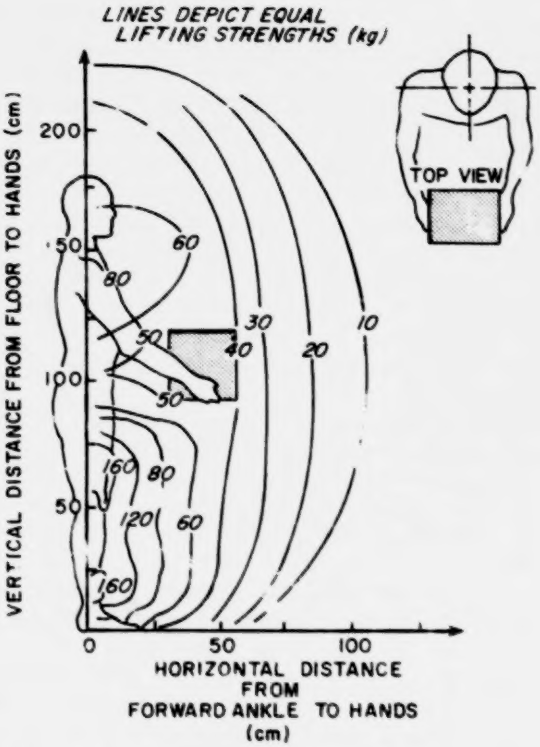


Figure 5.4: Predicted Lifting Strength of Large/Strong Male (Chaffin, 1974).

the muscle groups which limit performance on each task. Finally, it predicts the percentage of the male and female populations that could be expected to perform each job activity. The model has several assumptions which limit its usefulness:

1. The model selects the "best" posture in terms of maximal strength. Thus, it does not reflect additional stresses a person may receive due to poor posture selection.

2. Body weights and link lengths are based on 50th percentile anthropometry for men and women. Therefore, model predictions may be inaccurate for unusually large or small populations.

3. Lifting, may require certain amounts of dynamic strength depending upon acceleration, deceleration and speed of movement. This biomechanical model is based only on static strength capabilities. The relationship between static and dynamic strength is not well understood. Therefore, if the model is used to simulate a highly dynamic task, (e.g., one with jerking actions) the

predictions may overestimate capability (and underestimate stress on the low back, for example).

For additional information on this biomechanical strength prediction model, refer to Garg and Chaffin (1975). For an example application of the approach to industrial job analysis, refer to Chaffin, Herrin, Keyserling, and Garg (1977). This model was applied to the various situations described in the recommendations chapter. The comparative results are presented in the Appendix.

DYNAMIC STRENGTH

Another method for measuring the capacity of an individual to lift has been referred to in the literature as psychophysical strength. This is actually a misnomer since isometric strength (as discussed in the preceding section) is also psychophysical. Dynamic strength is a more appropriate name for this type of measurement even though time dependent forces and accelerations are seldom measured.

The measurement of dynamic strength using the "psychophysical approach" has been extensively used by several researchers (e.g., Snook, 1976, 1978; Snook and Irvine, 1968, 1969; Snook and Ciriello, 1974; Ayoub, et al., 1973, 1976, 1978; Strindberg and Peterson, 1972; Switzer, 1962; and Emanuel, et al., 1956) for determining different load handling capacities of individuals or groups of individuals.

Essentially, the subject is given control of one of the task variables, usually the weight of the object being handled. All other variables such as frequency, size, height, distance, etc., are controlled. The subject then monitors his own feelings of exertion or fatigue, and adjusts the weight of the object accordingly. The work tasks are made as realistic as possible with subjects tested in repetitive dynamic lifting tasks for several hours.

In each of these studies, subjects lifted industrial tote boxes with handles. The subject varied the weight of the box by adding or subtracting lead shot. In an attempt to minimize visual cues, each box contained a false bottom. The subject was aware of the false bottom, but never knew how much lead shot it contained. The amount of weight in the false bottom was randomly varied.

Subjects were instructed to work on an incentive basis, working as hard as they could without straining themselves, or without becoming unusually tired, weakened, overheated or out of breath. Several days of training sessions were usually required to allow subjects to gain experience at monitoring their own feelings, and adjusting the object weight.

The results of the seven manual handling studies conducted by Liberty Mutual Insurance Co. were recently summarized by Snook

(1978). The maximum acceptable weights for lifting tasks are given in Table 5.3 for male industrial workers, and in Table 5.4 for female industrial workers. For example, 18 kg is the maximum acceptable weight for 75% of the male workers lifting a rather large object (75 cm width) through a 76 cm distance from the floor to knuckle height once every minute. The equivalent value acceptable to 75% of female workers is 13 kg.* These values are based upon a freely chosen lifting posture where workers are not instructed to lift by any particular technique. An earlier experiment indicated that workers would not lift as much weight when required to maintain a straight back and bent knees. The maximum acceptable weights of lift are based upon objects with handles located in the middle of the width dimension.

Ayoub, et al., (1978) conducted a similar study to determine and model the lifting capacity of male and female industrial workers. Seventy-three male and 73 female subjects were used. Six different height levels and four frequencies (2,4,6, and 8 lifts/minute) were employed. The height levels were: (1) floor to knuckle; (2) floor to shoulder; (3) floor to reach; (4) knuckle to shoulder; (5) knuckle to reach; and (6) shoulder to reach as illustrated in Figure 5.5. The results of the study are summarized in Table 5.5.

A number of other studies are reported in the literature (e.g., Emanuel, 1956; Switzer, 1962; Whitney, 1958; etc.). Much of this earlier literature involves experiments with college students or air force personnel and will not be presented in detail.

DYNAMIC STRENGTH MODELS

Several researchers have used the psychophysical approach to develop lifting capacity prediction models (McConville and Hertzberg, 1968; McDaniel, 1972; Dryden, 1973; Knipfer, 1974; Ayoub and McDaniel, 1973; Ayoub, et al., 1973, Ayoub, et al, 1976a, Ayoub, et al., 1976b; Ayoub, et al., 1978; and Mital, et al., 1978).

Table 5.6 summarizes their models for lifting activities based on the psychophysical approach. These models lead to some interesting conclusions. According to the model developed by McConville and Hertzberg (1968), a person cannot lift a box which is 60 inches wide. Models developed by Poulsen (1970), McDaniel (1972), Dryden (1973), Knipfer (1974), Ayoub and McDaniel (1973), Ayoub, et al., (1973), Ayoub, et al., (1976a), Ayoub, et al., (1976b), Ayoub, et al., (1978), and Mital, et al., (1978) have one thing in common: lifting capacity is a function of isometric back strength. In these models, the independent variables do not include task variables. It should also be noted that most of these models do not include interactive effects.

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*It should be noted here that "width" for the Snook data means distance of the load away from the body measured in the horizontal axis (See fig. 8.3).

Table 5.3: Maximum acceptable weight of lift for males (kg) (Snook, 1978)

Width (a)	Distance (b)	Percent (c)	Floor to knuckle ht.						Knuckle to shoulder ht.						Shoulder to arm ht.					
			One lift every						One lift every						One lift every					
			5	9 s	14	1	5 min	8 h	5	9 s	14	1	5 min	8 h	5	9 s	14	1	5 min	8 h
		75	10	14	15	18	25	29	12	16	18	17	21	24	9	12	14	16	20	23
	76	50	13	17	19	22	30	36	14	19	21	21	27	30	11	15	18	20	25	28
		25	16	20	23	26	36	42	17	22	25	26	32	36	13	18	21	24	29	33
		75	11	14	16	19	26	31	13	17	19	20	24	27	10	14	15	18	22	25
75	51	50	14	18	20	23	31	37	15	20	23	24	30	34	12	17	10	22	28	31
		25	16	21	24	27	37	44	18	24	27	29	36	40	14	20	23	27	33	37
		75	13	17	19	21	29	34	15	20	22	23	28	32	11	16	18	21	26	30
	25	50	16	21	23	26	35	42	18	24	27	28	35	40	14	20	22	26	33	37
		25	19	25	28	31	42	50	21	28	32	34	42	47	17	24	27	31	39	44
		75	12	15	17	21	28	34	12	16	18	17	21	24	9	12	14	16	20	23
	76	50	15	19	21	26	35	42	14	19	21	21	27	30	11	15	18	20	25	28
		25	17	23	26	31	42	50	17	22	25	26	32	36	13	18	21	24	29	33
		75	12	16	18	22	30	35	13	17	19	20	24	27	10	14	15	18	22	25
49	51	50	15	20	22	27	37	43	15	20	23	24	30	34	12	17	19	22	28	31
		25	18	24	27	32	44	52	18	24	27	20	36	40	14	20	23	27	33	37
		75	14	18	21	24	33	39	15	20	22	23	28	32	11	16	18	21	26	30
	25	50	18	23	26	30	41	49	18	24	27	28	35	40	14	20	22	26	33	37
		25	21	28	31	36	49	59	21	28	32	34	42	47	17	24	27	31	39	44
		75	13	17	20	23	31	37	13	17	19	18	23	26	9	13	15	17	21	24
	76	50	17	22	25	29	39	46	15	20	23	23	29	32	11	16	19	21	27	30
		25	20	27	30	34	47	55	18	23	26	28	34	39	14	19	23	26	32	36
		75	14	18	20	24	32	38	13	18	20	21	26	29	10	15	16	19	24	27
36	51	50	17	23	26	30	40	48	16	21	24	26	32	36	13	18	20	24	30	34
		25	21	28	31	36	49	57	19	25	28	31	39	44	15	22	25	29	36	40
		75	16	21	24	27	37	43	16	21	24	24	30	34	12	17	19	23	28	32
	25	50	20	27	30	34	46	54	19	25	28	31	38	43	15	22	24	28	35	40
		25	25	32	36	40	55	65	22	29	33	37	45	51	18	26	29	34	42	48

(a) Width of object (cm) Note: horizontal hand location is at least (15 + width/2)
(b) Vertical distance of lift (cm)
(c) Percent of industrial population exceeding table value

Table 5.4: Maximum acceptable weight of lift for females (kg) (Snook, 1978)

Width (a)	Distance (b)	Percent (c)	Floor to knuckle ht.						Knuckle to shoulder ht						Shoulder to arm ht.					
			One lift every						One lift every						One lift every					
			5	9	14	1	5	8	5	9	14	1	5	8	5	9	14	1	5	8
				s		min		h		s		min		h		s		min		h
75	76	75	8	10	11	13	17	20	8	11	11	11	14	15	5	9	9	10	12	14
		50	9	12	13	14	20	23	9	12	12	13	16	18	6	9	10	11	13	15
		25	10	13	15	16	22	26	10	13	13	14	18	20	6	10	11	12	15	17
	51	75	8	10	12	13	18	21	9	12	12	12	15	17	6	10	11	11	14	15
		50	9	12	14	15	20	24	10	13	13	14	18	20	6	11	12	12	15	17
		25	10	14	15	17	23	27	11	14	14	16	20	22	7	12	13	13	17	19
	25	75	9	12	14	15	20	24	11	14	14	15	18	20	7	11	13	13	16	18
		50	11	14	16	17	23	27	12	15	15	17	21	23	8	13	14	14	18	20
		25	12	16	18	19	26	31	13	17	17	19	23	26	8	14	15	16	20	22
49	76	75	9	11	13	15	20	24	8	11	11	11	14	15	5	9	9	10	12	14
		50	10	13	15	17	23	27	9	12	12	13	16	18	6	9	10	11	13	15
		25	11	15	17	19	26	31	10	13	13	14	18	20	6	10	11	12	15	17
	51	75	9	12	13	15	21	25	9	12	12	12	15	17	6	10	11	11	14	15
		50	10	13	15	17	24	28	10	13	13	14	18	20	6	11	12	12	15	17
		25	12	15	17	20	27	32	11	14	14	16	20	22	7	12	13	13	17	19
	25	75	10	14	15	17	23	28	11	14	14	15	18	20	7	11	13	13	16	18
		50	12	16	18	20	27	32	12	15	15	17	21	23	8	13	14	14	18	20
		25	14	18	20	22	30	36	13	17	17	19	23	26	8	14	15	16	20	22
36	76	75	10	13	14	16	22	26	9	12	12	12	14	17	6	9	10	11	13	15
		50	11	15	17	19	25	30	10	13	13	14	17	19	6	10	11	12	15	16
		25	13	17	19	21	28	34	11	14	14	15	19	21	7	11	12	13	16	18
	51	75	10	13	15	17	23	27	9	12	12	13	17	19	6	10	11	12	15	17
		50	12	16	17	19	26	31	10	14	14	15	19	21	7	11	13	13	16	18
		25	14	18	20	22	30	35	11	15	15	17	21	24	8	12	14	14	18	20
	25	75	12	16	18	19	26	31	11	15	15	16	19	22	8	12	14	14	17	20
		50	14	18	20	22	30	35	12	16	16	18	22	25	8	14	15	16	19	22
		25	16	21	23	25	33	40	13	18	18	20	25	29	9	15	16	17	21	24

(a) Width of object (cm) Note: horizontal hand location is at least (15 + width/2).
(b) Vertical distance of lift (cm)
(c) Percent of industrial population exceeding table value

Table 5.5: Mean and standard deviation of maximum weights (kg) of lift acceptable to male and female industrial workers (corrected for one lift/min.).

Height of Lift	Sex	Mean	Standard Deviation
Floor to knuckle	Male	28.0	7.66
	Female	16.9	3.06
Floor to shoulder	Male	23.3	5.50
	Female	14.1	2.97
Floor to reach	Male	22.3	5.09
	Female	12.8	2.46
Knuckle to shoulder	Male	26.1	6.67
	Female	14.5	2.98
Knuckle to reach	Male	24.3	4.86
	Female	11.9	2.21
Shoulder to reach	Male	19.8	4.75
	Female	11.7	1.90

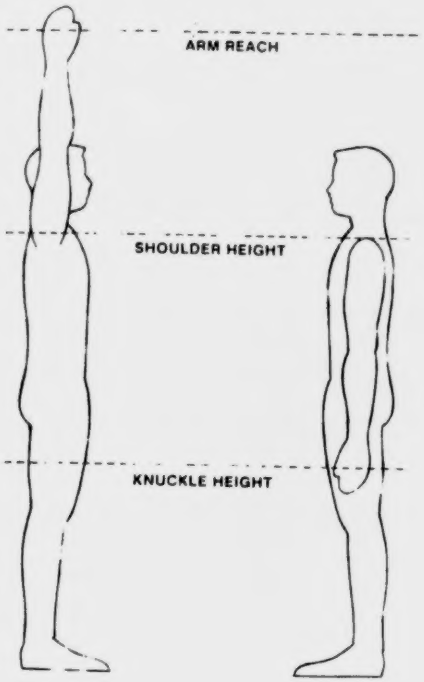


Figure 5.5: Classification of Lifting Height

Table 5.6: Summary of dynamic strength regression models

Researchers	Dependent Variables	Height Level	Male	Female	Both	Model
McConville & Hertzberg, 1968	Load of lift	Floor to knuckle	X			Predicted lift = 0-X;
Poulsen, 1970	Maximum weight of lift	Floor to table			X	Predicted lift = 1.4 (Max. Isometric Back st.) - 0.5*Body Wt.;
		Table to head			X	Predicted lift = 0.5 (Sum of the right and left max. isometric arm push);
McDaniel, 1972	Load of lift	Floor to knuckle	X			Predicted lift = -172.3599+0.022*Height^2 -2.728*Static End.^{2} +-.0209*RPI*Arm St. +0.0534*RPI*Back St.-2.5134 (FI/Dynamic End.);
	Load of lift	Floor to knuckle		X		Predicted lift = -24.0268+0.1936*RPI^2 +0.00607*Arm St.* Log St.;
	Load of lift	Floor to knuckle			X	Predicted lift = 11.934-1.12*Back St +0.158(RPI^2+0.0046* Back St.^{2}-8.807*Static End.^{2}-0.095*Sex* FI +0.06*Height*RPI+0.0[illegible] *RPI*Leg St.
Dryden 1973	Load of lift	Knuckle to shoulder	X			Predicted lift = 0.82766*Chest Circumference+0.55885*Dynamic End;
	Load of lift	Knuckle to shoulder		X		Predicted lift = 3.8092*RPI-1.473*Height *FI/1000-0.31199*RPI*Stat. End.+1.228*Percent Fat* FI/1000;
	Load of lift	Knuckle to shoulder			X	Predicted lift = 25.1212+0.37912*Sex* Dynamic Eng.;
Knipfer, 1974	Load of lift	Shoulder to reach	X			Predicted lift = 4.983+0.197*Back St. -0.0177*Shoulder St. +0.429*Age,
	Load of lift	Shoulder to reach		X		Predicted lift = 15.071+0.343*Weight +0.839*Dynamic End.+ 0.355*Foream Circumference;
	Load of lift	Shoulder to reach			X	Predicted lift = 5.225*Sex+0.00494*Shoulder St.+0.1944*Horizontal Push St.;

Table 5.6: (cont.)

Researchers	Dependent Variables	Height Level	Male	Female	Both	Model
Knipfer, 1974 (continued)	Load of lift	Floor to knuckle; knuckle to shoulder, shoulder to reach			X	Predicted lift = 13.19226+13.85436*Sex +0.25741*Dynamic End.;
Ayoub et al., 1978 and	Load of lift+body wt.	Floor to knuckle			X	Predicted lift = -63.776-30.793*Sex+ 23.922*Weight Code- 0.509*Age+1.235*Shoulder Ht.+0.087*Back St.+4.902 Abdominal Depth;
Mital et al., 1978	Load of lift+body wt.	Floor to shoulder			X	Predicted lift = -129.615-20.278*Sex+12.51* Weight Code-0.488*Age +1.429*Shoulder Ht. +0.124*Back St.+6.294* Abdominal Depth;
	Load of lift+body wt.	Floor to reach			X	Predicted lift = -42.372-22.184*Sex+16.983* Weight Code-0.711*Age+ 0.835*Shoulder Ht.+0.125* Back St.+6.022*Abdominal Depth;
	Load of lift+body wt.	Knuckle to shoulder			X	Predicted lift = 60.312-22.1[illegible]*Sex+11.612* Weight Code-0.4[illegible]*Age+ 0.877*Shoulder Ht.+0.165* Back St.+6.267*Abdominal Depth;
	Load of lift+body wt.	Knuckle to reach			X	Predicted lift = -102.799-21.387*Sex+ 17.537*Weight Code-0.318* Age+1.317*Shoulder Ht. 0.094*Back St.+5.315* Abdominal Depth;
	Load of lift+body wt.	Shoulder to reach			X	Predicted lift = -40.415-20.511*Sex+20.737* Weight Code-0.508*Age+ 0.942*Shoulder Ht.+0.117* Back St.+[illegible].704*Abdominal Depth

All U.S. units of measure

X = width of the box in inches

RPI = Body Ht./ $\sqrt[3]{\text{Body Wt}}$

$$FI = \frac{100 \text{ x duration of the step exercise (seconds)}}{2\text{x pulse recovery sum}}$$

Models developed by Poulsen (1970), McDaniel (1972), Dryden (1973), Knipfer (1974), Ayoub and McDaniel (1973), Ayoub, et al., (1973), Ayoub, et al., (1976a), Ayoub, et al., (1976b), and McConville and Hertzberg (1968) have their obvious limitations. They are applicable to only one or two height levels for lifting in the sagittal plane and are developed by collecting data at only one frequency of lift. Some of these limitations have been overcome in the models developed by Ayoub, et al., (1978) and Mital, et al., (1978), but still the models are for lifting in the sagittal plane.

Some disagreement between the results of these studies can be observed. According to McDaniel (1972) and Dryden (1973), males and females should not be used together in the same model to predict the acceptable weight of lift. Their conclusion was different from the one drawn by Knipfer (1974). According to his results, the combined model predicts the lifting capacity as well as the individual models. According to Ayoub, et al., (1978) and Mital, et al, (1978) the combined models predicted lifting capacity better than individual models.

PSYCHOPHYSICAL DESIGN CRITERIA

Table 5.7 combines the most recent studies of Snook (1978) and Ayoub, et al., (1978) in predicting average lifting capacity of 75 percent of industrial women and 25 percent of industrial men.

These quartiles were selected to represent the inherent variability within the industrial population. Based on the epidemiological evidence presented in Chapter 2, the majority of low back injuries were shown to occur on jobs that were not acceptable to more than 75 percent of the population (Snook, 1978). Therefore, if the workforce was predominantly women, this percentile specification should be protective. For an all male workforce this limit would be overly restrictive. Further, were individuals tested for strength capability, an even greater capacity could be expected. The choice of a 25th percentile male is arbitrary, but assumed reasonable based on the reliability of available testing methods.

The values presented in Table 5.7 were arrived at by adjusting Snook's data (1978) for box size and frequency and then combining it with the lifting capacity data generated by Ayoub, et al., (1978). A linear box size (horizontal location of the hands in the sagittal plane) and frequency effect were assumed for interpolation and extrapolation. These values were further adjusted to show a linear frequency effect.

For the floor to shoulder height, floor to reach height, and knuckle to reach height levels, the lifting capacity values recommended by Ayoub, et al., (1978) were used for frequency adjustment since no other data exist for these height levels. The standard deviation assumed in Table 5.7 is the larger of the values generated by

Table 5.7: Maximum recommended weights based on dynamic strength (Kg.)

			Female		Male .	
Height of Lift	Horz. (cm)	Freq. (lift/min)	25%ile	50%ile	50%ile	75%ile
Floor to knuckle	30	1	18	20	30	36
		2	17	18	28	34
		4	14	16	24	28
		6	12	14	22	28
		8	11	13	21	26
		12	9	11	18	21
	38	1	15	17	27	32
		2	11	13	26	31
		4	10	13	24	30
		6	10	12	22	25
		8	10	12	20	24
		12	9	10	15	18
	46	1	13	16	24	29
		2	11	13	23	27
		4	11	12	21	26
		6	11	12	20	23
		8	10	11	18	23
		12	8	10	14	17
Floor to shoulder	30	2	11	13	23	27
		4	12	13	22	25
		6	11	13	20	24
		8	11	13	19	23
	38	2	12	14	24	26
		4	11	13	23	27
		6	9	13	22	25
		8	10	12	21	25
	46	2	11	13	23	26
		4	11	13	22	25
		6	10	12	21	24
		8	9	11	20	25
Floor to reach	30	2	11	12	21	24
		4	10	12	20	24
		6	11	11	19	21
		8	10	11	18	20
	38	2	11	13	24	29
		4	11	12	21	25
		6	10	11	18	21
		8	10	11	15	17
	46	2	10	12	18	22
		4	9	11	18	20
		6	9	11	17	20
		8	9	10	17	20

Table 5.7: (cont.)

			Female		Male	
Height of Lift	Horz. (cm)	Freq. (lift/min)	25%ile	50%ile	50%ile	75%
Knuckle to shoulder	30	1	13	14	24	29
		2	12	14	23	27
		4	12	13	22	26
		6	11	13	20	24
		8	9	12	18	22
		12	9	10	15	18
	38	1	12	13	27	31
		2	11	13	26	30
		4	12	13	24	28
		6	11	13	22	27
		8	9	11	20	24
		12	8	9	14	17
	46	1	11	13	21	25
		2	11	13	20	25
		4	10	12	19	24
		6	9	11	18	24
		8	9	10	17	21
		12	8	9	14	17
Knuckle to reach	30	2	10	13	21	26
		4	10	12	20	22
		6	10	12	18	21
		8	9	11	17	19
	38	2	11	12	24	27
		4	11	12	22	24
		6	10	11	20	22
		8	10	11	18	21
	46	2	13	14	24	28
		4	11	13	22	24
		6	11	12	20	21
		8	9	11	18	20
Shoulder to reach	30	1	11	12	23	27
		2	10	12	22	24
		4	10	11	21	25
		6	9	10	19	22
		8	7	8	15	18
		12	6	6	11	14
	38	1	10	11	20	24
		2	9	11	19	22
		4	9	10	18	22
		6	8	9	17	22
		8	6	8	15	18
		12	5	6	11	13
	46	1	11	12	20	24
		2	10	11	18	22
		4	9	10	18	21
		6	9	10	17	21
		8	8	9	15	18
		12	5	6	11	13

Ayoub, et al., (1978) and Snook (1978). The horizontal location of the hands is assumed to be 1/2 the horizontal box size plus 15 centimeters for body clearance.

A similar illustration of the effects of object size (horizontal and vertical location of the load) on the isometric strength capabilities of these two population percentiles is presented in Figures 5.6 and 5.7. These figures are based on the biomechanical model of Chaffin, et al., (1978) discussed earlier in this chapter. They apply for occasional lifts (less than 1 lift per 5 minutes).

Depending on the specific task (weight handled, vertical and horizontal hand location, vertical lift distance, and frequency of lifting) different guidelines would be suggested based on isometric versus dynamic strength. Both are required for safe lifting. The guideline presented in Chapter 8 is evaluated in terms of both isometric and dynamic strength capacities in the Appendix.

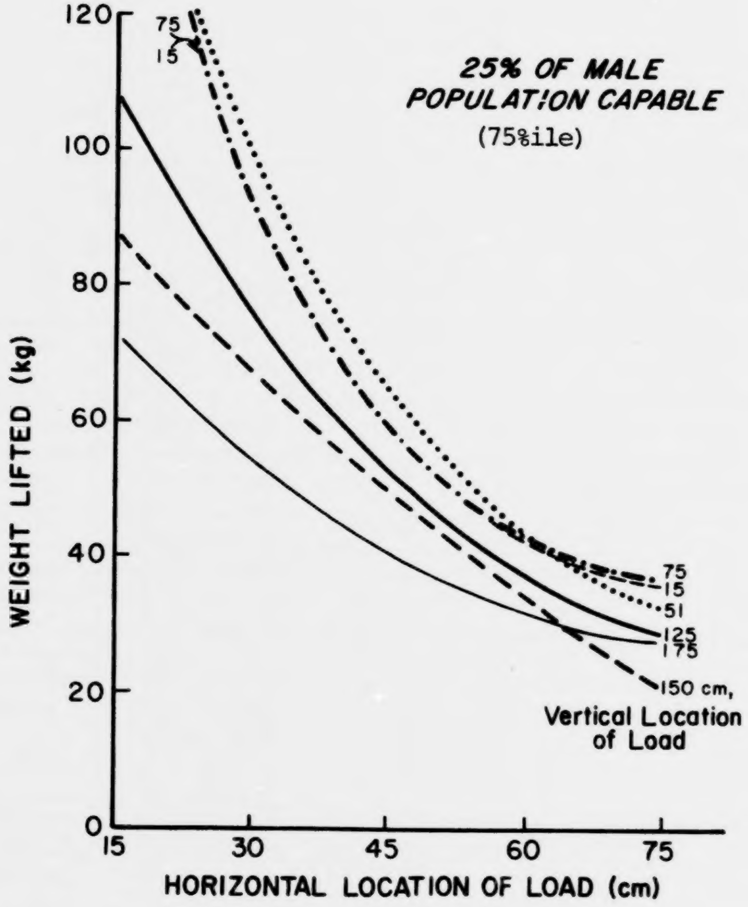


Figure 5.6: Maximum Recommended Weights Based on Male Isometric Strength

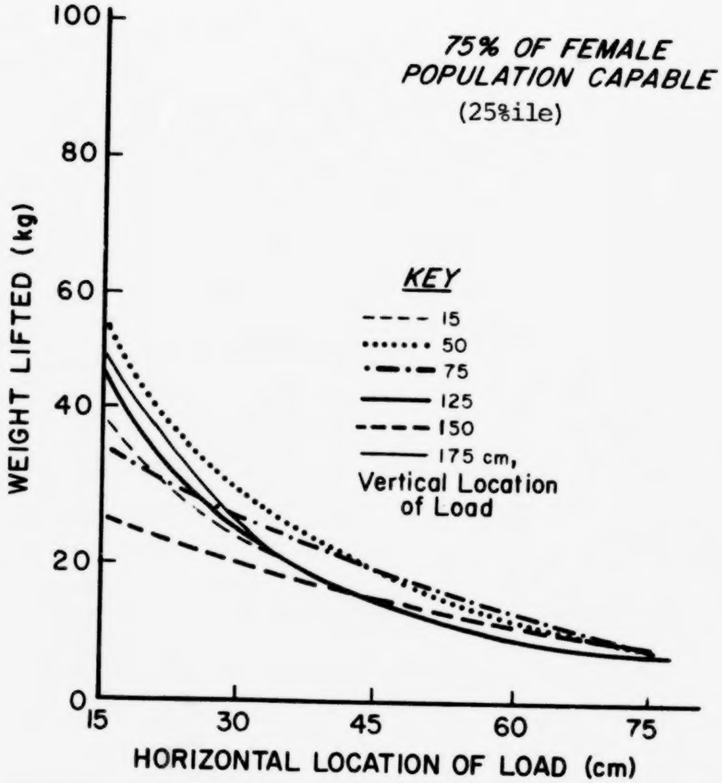


Figure 5.7: Maximum Recommended Weights Based on Female Isometric Strength

It is also interesting to note that the psychophysical criteria discussed in this chapter lead to slightly different conclusions than the physiological criteria in Chapter 4. Figure 5.8 shows the trade-off between weight lifted and frequency of lift observed by Snook (1978) using the psychophysical approach compared with the continuous work capacities predictions of Lind, et al., (1977) using the physiological approach. Based on lifting from the floor to knuckle height, Snook observed that workers were willing to work above 35% of their aerobic capacity($\dot{V}_{O_2}$ max) when lifting more frequently than 6 times per minute, but well below that level with infrequent lifts.

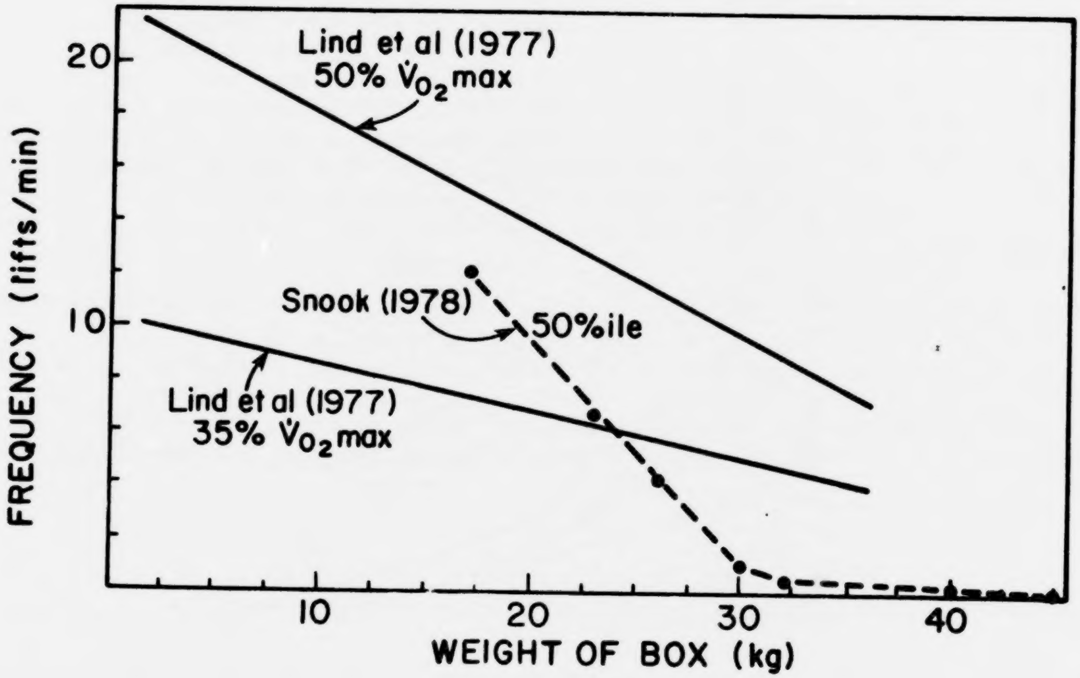


Figure 5.8: Comparison of Physiological and Psychophysical Criteria.

Two major points can be drawn from this illustration. First, for low frequency lifting, capacities are limited by strength rather than endurance criteria. Second, endurance is a function of work duration. For continuous 8 hour lifting, the metabolic criteria of Chapter 4 need to be applied to avoid fatigue. For occasional high frequency lifting the psychophysical limits developed in this Chapter are more appropriate.

CHAPTER 6

ADMINISTRATIVE CONTROLS

As discussed in Chapters 3-5, a large variation in lifting capacity exists in the working population. One must be conscious of the fact that with any ergonomic criterion (e.g., strength, aerobic capacity, etc.) it is often true that the standard deviation of any general population sampled will be between 30 and 40 percent of the mean of the population attribute measured.

Such a large variation in the population's tolerance to physical stress supports the need for administrative controls to assure that both,

1. a worker who is either weak or unfit is not exposed to the demands of lifting heavy loads, or,
2. a strong, fit worker is suitably trained to avoid certain lifting posture and activities which are believed to increase the hazard level.

This chapter develops guidelines for selection and training of such workers who are to be placed on jobs requiring the lifting of materials.

SELECTION OF WORKERS

Present selection procedures vary widely. A large number of smaller manufacturing, distribution and service industries have neither medical nor nursing staffs, and no formal selection system exists. The principal method has been self-selection by the worker based on their initial tolerance for the demands of the job. In larger industries, new employees are often asked to complete a questionnaire on health and medical history; and are submitted to routine tests of visual, auditory and pulmonary function, of blood pressure, mobility, etc., often with the addition of a chest X-ray. A physician will only see those whose replies and test results reveal abnormality or doubt on the part of the test administrator. In a few large industries, every recruit is examined by a physician but this usually depends on the existence of recognized physical or environmental hazards.

The clinical examination is widely regarded as the first essential step in a good selection procedure for physical labor (Magnussen and Coulter, 1921; Becker, 1961; Moreton, et al., 1958; McGill, 1968; Rowe, 1971) and it is generally agreed that the primary aim is to identify those who have had previous episodes of back or sciatic pain. This is based on the finding that the probability of episodes of back pain increases by a factor of 3 or 4 after the first reported attack (Dillane, et al., 1966). However, other than the scars of surgery, there are few reliable and objective signs of previous back problems, and the medical history is often of skeptical value for this purpose (Rowe, 1971).

After some type of evaluation, assuming no gross abnormalities have come to light, new employees are certified as fit for general work, still subject to training. It is comparatively rare, unfortunately, that the orientation and training period is under medical supervision. It is proposed that with such supervision during the first few days on the job, many postural stress related problems could be prevented. Clearly, for any physical work which is unfamiliar, a period of adaptation and conditioning is needed. Tolerance for postural stress, and for kinetic stress arising from rapid trunk movements, is likely to increase over a period of days or weeks. Similarly, the magnitude and frequency of the loads which can be handled without discomfort may increase with physiological adaptation and the acquisition of skill. However, the processes of adaptation to postural induced kinetic stresses may lag (scientific evidence is limited in this regard).

It is recognized that selection must be concerned with both the initial screening and placement of employees and their acclimitization to the physical stresses of the job. Further, very few companies are now capable of such aggressive management. Fortunately, some are developing and evaluating formal selection/placement/conditioning and training programs. It is clear that these efforts must be encouraged.

Criteria for Physical Assessments

There are many different methods by which a concerned physician may evaluate a person's capability to handle heavy loads safely in a future job. Some of these methods may have merit. Others are of questionable value. In providing any such assessment it is important that certain medical, social, economic, and legal criteria must be met. In choosing between alternative methods, it is suggested that the following criteria be applied:

1. Is it safe to administer?
2. Does it give reliable, quantitative values?
3. Is it related to specific job requirements?
4. Is it practical?
5. Does it predict risk of future injury or illness?

Is the test safe to administer? Perhaps one of the most widely used procedures in the past for evaluating a person's physical capability, the low-back X-ray, provides an example of these criteria. As will be discussed later in this section, the evidence which supports the use of such X-rays for routine pre-employment and placement screening is usually insufficient to warrant the procedure, especially when the radiation hazard is considered.

Tests of a person's physical strength and endurance have also become popular in many industries, primarily because they can meet some of the other criteria. It is imperative that such tests be carefully evaluated to assure that they are safe. For instance, a test which sets a specific goal for the worker, (i.e., the person must lift an object of specified weight to obtain a job), is a situation which may produce overexertion injury in an overly motivated subject. On the other hand, if there is no specific goal stated or direct feedback given as to how great the exertion is during the test, as recommended by the AIHA Ergonomics Committee (Caldwell, et al., 1974), isometric strength testing has proven to be safe in several studies (Chaffin, 1974; Chaffin, et al., 1978; Laubach, 1976). It is recommended, however, that any such tests be included as part of a medical examination only after the person's medical history has been screened for any past history of musculoskeletal or coronary problems, and a general physical examination has been performed.

Does the test give reliable, quantitative values? Though clinical impression is important in assessing a person's physical capability, specific tests with quantitative scoring should be performed. Stereotypes based on age, gender, and body weight have all been shown to be only weakly correlated with physical capability to exert high forces (Chaffin, et al., 1978; Bernauer, et al., 1975; Laubach, 1976, and Kamon, et al., 1978).

A test of physical capability, like any other diagnostic test, should produce repeatable results. A common measure of such is the coefficient-of-variation of the repeated tests, which is the standard deviation of the repeated values divided by their mean value. This is expressed as a percentage, and thus, represents the percent error in the test due to measurement procedures. It should be possible in physical capability tests to achieve a coefficient-of-variation of less than 15% (Chaffin, et al., 1977), with well-controlled laboratory tests often achieving 5%.

Is the test related to specific job requirements? It has been disclosed by several studies that one physical attribute of a person does not correlate well with another. For instance, grip strength is a poor predictor of other strengths (Laubach, 1976). Considering anthropometric and specific strength values together, one can achieve a better prediction of the strength scores achieved by people performing physical acts common to industry but a high unexplained variance (about 27%) remains even when five or six attributes are combined (Chaffin, et al., 1977).

The exact nature of the physical task required of a person dictates which physical attributes are important. In one task, functional reach overhead may be important. In another, lifting, pushing, or pulling force capabilities are essential. To designate which one is most relevant to selection, it is necessary to evaluate carefully the job physical requirements as outlined later in Chapter 8. In this same regard, it is a legal requirement that such tests be job related to assure that they do not discriminate against women, minorities, aged workers, or the physically disabled (Miner, et al., 1978).

Is the test practical? To be used, a selection procedure must be practical. What is necessary in one industry may not be needed in another. Smaller industries may be able to construct a set of carefully controlled tests of a person's physical capability while the person is learning the job during the first couple of days or weeks on the job. Larger industries may need more standardized tests under more clinical settings to assess large numbers of job applicants. These should meet the following practical conditions:

1. Require minimum hardware expense.
2. Have hardware capable of simulating different job conditions.
3. Require minimum time to administer.
4. Require minimum instruction and learning time.

Does the test predict risk of future injury or illness? This criterion is probably the most difficult one to meet. It requires continual evaluation of new selection methods using epidemiological studies in industry. Injury and illness data supporting any selection and placement procedure are necessary. Once a procedure is chosen, careful evaluation of its potential effect on injury and illness data should be instigated to assure that it meets the desired goal of reducing health and safety problems. Such an evaluation must consider the degree of matching of a worker's physical capabilities (as measured by the proposed test) with the job physical demands. After a period of time, injury frequency and severity rates can then be compared for both those that are well matched and for those that are not well matched.

Radiological Screening

There has been considerable zeal amongst a number of occupational medical advisors for routine lumbar spinal radiography as a prerequisite for employment in heavy manual work (Stewart, 1947; Colcher and Hursh, 1952; Becker, 1955; 1961; Kosiak, et al., 1966; McGill, 1968; Bimlett, 1972; Moreton, 1974). Elsewhere the enthusiasm waned and it is considered by many to be unwarrantable

(Wilkins, et al., 1957; Redfield, 1971; Harley, 1972; Montgomery, 1976) if not condemned out of hand (Houston, 1977). At a conference on this topic in 1973, sponsored by the American College of Radiology, the American Academy of Orthopaedic Surgeons and the Industrial Medical Association, low back X-rays without prior clinical examination were deplored. It was agreed that no worker should be rejected solely on the basis of radiological appearance and that the conference recognized that low back X-rays had yet to be proved as having reliable predictive value. In a recent American Occupational Medical Association (AOMA) association affairs committee report (1979), it was concluded that "lumbar spine X-ray examinations should not be used as a routine screening procedure for back problems, but rather as a special diagnostic procedure available to the physician on appropriate indications for study."

LaRocca and Macnab (1969), Rowe (1969), Troup, et al., (1974) and Magora and Schwartz (1976) have found no statistically significant differences in the incidence of ra-iological abnormalities between workers with known history of back or sciatic pain and those without. One study by Redfield (1971) reported a lower incidence of back pain in a group of workers who had been identified as radiologically of 'high-risk' than in a group with normal radiological appearance. For the majority of industrial purposes, however, pre-employment radiological screening cannot be justified on statistical grounds and due attention must be paid to the hazards of radiation.

The criteria upon which radiological screening is deemed necessary thus depend on the definition of an abnormally high risk of back injury. To take an extreme example from the armed forces: pilots may have to be ejected from fighter aircraft in an emergency, and this carries a high risk of spinal fractures - some of which damage the spinal cord. Experimental work has shown that the presence of some radiological abnormalities (for example, Schmorl's nodes, which can safely be ignored in most clinical situations) may adversely affect the capacity of the spine to withstand the acceleration on ejection (Kazarian, 1978). Such risks can reasonably be defined as unacceptable and radiological screening is well justified. Moreover exceptionally high radiographic standards are needed to achieve the definition required (for example, an enema may be needed before being X-rayed if the image is not to be obscured by flatus).

As far as industry is concerned, there may be jobs entailing a high risk of back injury due to MMH, but it is not possible to define a criterion for the need for radiological screening. Cases must be assessed on their own merits and with due regard to current radiological opinion and radiographic practice. When low-back X-rays are considered justifiable, the informed consent of the individual is essential. (It should be noted that gonadal protection cannot be adequately achieved in women for this purpose and thus a higher risk for them must be considered).

Even where low-back X-rays are deemed acceptable, there remains the problem of interpretation. An Ad Hoc Committee on Low Back X-rays

(1964) proposed some radiological criteria for job-placement based on a consensus of opinion (since there were no reliable data on the predictive rating for the observed abnormalities). Such data are still nonexistent. It is impossible to quote a value for the increased probability of back trouble for each abnormality. One partial exception is the case of scralisation studied extensively by Tilley (1970). He studied lost work-time due to back pain in 7,236 workers who had pre-employment X-rays: 1013 (14%) had sacralisation and as a group their average lostwork-time of 3.4 days/year did not differ from the normal. When the group was subdivided, some types of sacralisation were associated with less than the average lost work-time (e.g., bilateral sacralisation and fusion - 2.4 days/year) and others with aboveaverage (e.g., pseudarthrosis one side and fusion the other - 4.6 days/year). Even in this case there is hardly an adequate basis for advising anyone not to take a given job based solely on this positive sign.

Spondylolisthesis is more generally assumed to be a 'high-risk' abnormality, particularly in the younger worker (Parvi and Virolainen, 1975). However, in none of the many published series in which its incidence is recorded has there been any attempt to differentiate by cause [i.e., spondylolytic, dysplastic, degenerative, etc., (Wiltse, et al., 1976); by vertebral level, despite the widely varying prognostic implications [clinically, those at $L_{4/5}$ are more likely to have neurological dysfunction than those at L_5/S_1 (Jackson, et al., 1977); or, in the case of spondylolysis, in terms of its structural stability (Hirabayashi, et al., 1972; Troup, 1976].

A third aspect of the interpretation of lumbar spinal radiographs concerns the size and shape of the spinal canal and intervertebral foramina. Computer-assisted tomography is a technically elegant way of assessing these dimensions. There is evidence that those with sciatic pain or symptoms due to stenosis have narrower canals and foramina than the normal population (Porter, et al., 1980). The phenomenon is not one of general narrowness in all dimensions because there is evidence that the different measurements (mid-sagittal diameter, interpedicular distance, pedicular length or foraminal AP, and interfacetal distance) are independent variables (Troup, et al., 1974). The predictive significance of these measurements to back or sciatic pain is not yet known, though Troup, et al., (1974) found an inverse relationship between previous sciatic pain and AP foraminal diameter.

In summary, with present knowledge of the prognostic significance of radiological abnormality, employment advice should be given with caution, and then only by an experienced physician or surgeon after a thorough interview and examination, and with full knowledge of the postural, kinetic and handling stresses of the MMH job concerned.

Strength Testing

Many industries have jobs that require occasional lifting, wherein for a few seconds a high amount of force is required. Common examples are loading stock into a machine, picking-up a tote pan full of parts, lifting a broken machine component during maintenance, or replacing the dies in a press. The activities are often not frequent enough, or they can be paced by the worker so that endurance, in the cardio-pulmonary sense, is not the limiting factor. Rather, one is concerned with the brute force required to successfully and safely accomplish the task.

Recent studies have indicated that such force requirements increase both the frequency and severity of musculoskeletal problems, and particularly low-back pain incidents in industries of various types (Hult, 1954; Chaffin, et al., 1977; Miner, et al., 1978). These studies and others have substantiated the need to more carefully select and place employees on jobs requiring high forces. What follows is a description of the development of isometric strength tests for this purpose. It is presented as a better example application of the preceding criteria.

The first step in developing a selection program is to determine whether such is applicable. This determination often occurs in two phases. First, the medical and/or safety functions should perform a statistical analysis of musculoskeletal problems in the organization and determine if these problems are particularly prevalent and/or severe. As reported in Chapter 1, a recent analysis of compensation injuries in the state of Arkansas disclosed that approximately one-third of all injuries and illnesses reported in all industries were musculoskeletal strains and sprains (Bureau of Labor Statistics, 1976). Some industries, however, report a prevalence of over 60%. Once it is decided that the prevalence and/or severity data are excessive, then a second phase of analysis is initiated. This involves a further statistical analysis of the injury data to determine if certain jobs (known to require high exertions) have higher injury frequency rates and severity rates than the more sedentary jobs in the plant.

At this point, a job analysis as outlined in Chapter 8 should be initiated to determine actual job requirements. These data should be gathered in the systematic way described in Chapter 8 and made part of the job description record.

Without a specific physical description of the job it is not possible to develop a valid selection/placement procedure. Variations in work postures will result in specific stresses on the musculoskeletal system. A test of one type of strength selected for its administrative simplicity may not predict the type of strength required on the job if the test does not also reflect the most strenuous postures required on the job. Given that the job strength requirements are documented for those jobs having high musculoskeletal problems, then valid tests of employees can be developed.

Isometric strength tests are preferred due to the safety criterion. In an isometric test the subject is required to slowly increase the force exerted until they reach a level which "feels" safe. No specific feedback or challenges are given during the testing. This procedure has been proposed in an AIHA Ergonomic Guide as being a safe and reliable procedure (Chaffin, 1975). It has been used in a number of industrial studies (see Chapter 5) testing over 3000 individuals and no injuries have been reported with the above procedure.

As to whether such testing is a valid indicator of potential risk of future injury, two longitudinal studies have been performed. Collectively, these have involved nearly 1,000 workers in both a light and heavy products industries (Chaffin, 1974; Chaffin, et al., 1978). These studies have revealed that both frequency and severity rates of musculoskeletal problems were about three times greater for those workers who were placed on jobs that required physical exertions above that demonstrated by them in the isometric strength tests, when compared with workers placed on jobs having exertion requirements well below their demonstrated capabilities.

The practicality of strengh testing depends on the sophistication of the medical and personnel functions. An isometric strength testing apparatus can be purchased for between one and four-thousand dollars, depending upon the sophistication and reliability required. A space in the medical department must be provided which is private. A nurse or medical technician needs to be trained to perform the tests following the directions proposed in the AIHA Ergonomics Guide (Chaffin, 1974). Instructions and administration will normally require between 14 and 30 minutes depending on the number of tests.

Perhaps more important than the time and capital outlay for the testing apparatus, however, is the need to have the jobs evaluated in a way that dictates which types of strength tests are applicable. This requires a close coordination of the medical function and the work practice or industrial engineering functions. The latter groups must perform a rigorous evaluation of the high incidence jobs and document the actual strength requirements, even on "occasional lifting tasks". In so doing, they must also assure that the tasks so documented cannot be easily modified to reduce the physical demands. In other words, the tasks must be truly inherent to the processes, and as such, require excessive capitol expenditure to redesign.

Aerobic Capacity Testing

The physical endurance of the worker becomes critical when the job requires much high frequency, whole-body activity. When this is the case, it is important that the individual involved can sustain the required level of activity for an extended period of time without fatigue. To achieve this the individual must be able to intake enough oxygen and transport it through the blood stream at a rate sufficient to meet the oxygen demands of the active muscles.

As was noted in Chapter 4, when oxygen is not available to the muscles, lactic acid is produced, contractile abilities rapidly decrease and eventually the muscles can no longer generate significant force. Aerobic capacity testing is one means for assessing this dimension of individual physical fitness (as proposed by the American Heart Association (1972) and the American Industrial Hygiene Association (Kamon and Ayoub, 1976)).

A person's aerobic capacity corresponds to the maximal oxygen uptake rate, which is accompanied by the maximal attainable heart rate, for that individual. One can determine a person's aerobic capacity by monitoring the oxygen uptake and heart rate while increasing the work load in a controlled manner. Common devices for this are motor driven treadmills, stationary bicycles and benches which are used for stepping. The maximal oxygen uptake is determined by noting the value at which the oxygen uptake stops climbing as the work load increases. Since the conversion factors between oxygen uptake level and metabolic rate have been established, one can convert the maximal oxygen uptake to the maximal aerobic metabolism rate (also commonly called the maximal aerobic power or aerobic capacity).

Maximal aerobic capacity testing, as described above, is quite stressful. Often the test is run until the person cannot continue due to exhaustion. Since this condition may present a serious medical risk, sub-maximal testing is often employed instead.

Sub-maximal aerobic capacity testing consists of measuring oxygen uptake and heart rate at two to three work loads ranging between 50% and 75% of the worker's expected aerobic capacity and extrapolating. A population based estimate of expected maximum heart rate (based on the worker's age, sex and physical fitness) is then used to estimate the maximal oxygen uptake. This extrapolated value is then converted to an estimate of aerobic capacity. Since an individual's maximal heart rate may vary as much as ± 20 beats per minute from tabulated population values, a 10 to 15% error can accrue for the estimated maximal oxygen uptake (Kamon and Ayoub, 1976). Thus sub-maximal testing is not as accurate as maximal testing.

Aerobic capacity testing needs to be undertaken with caution, especially if it involves submitting the individual to a workload corresponding to his or her maximal aerobic power. Obviously, maximal testing should only be done under the most careful attention of a physician. Sub-maximal testing is not as risky but still should only be undertaken with healthy individuals who have been ascertained by a physician to have no cardiovascular impairments or indications of infectious diseases including the common cold.

Metabolic requirements for jobs can be estimated using the methods described in Chapter 4. These requirements can then be compared to the individual's aerobic capacity after adjustment for work period duration to determine the relative stressfulness of the job.

Aerobic capacity testing is most appropriate for jobs that involve relatively continuous, dynamic work. For activities such as lifting, holding and carrying a significant amount of static work is also performed. Thus, the above testing methods and comparisons may not be very accurate. Preliminary studies indicate that more research is needed before good evaluation techniques for the metabolic cost of mixed static and dynamic tasks will be available. At present, applying capacity estimates based on dynamic testing to jobs with both static and dynamic tasks will not necessarily be protective.

In terms of practicality, numerous variations in aerobic capacity testing procedure exist. The primary differences are in the sophistication of hardware required and the time needed to complete the test (Kamon and Ayoub, 1976). As would be expected, the major trade-off is between accuracy and cost. Procedures can take anywhere from fifteen minutes to approximately an hour and involve nothing more than a simple step device or require relatively elaborate heart rate monitoring and gas analyzers.

SELECTION OF WORKERS - SUMMARY

The assessment of a worker who performs manual lifting must include specific tests of physical capability. Such tests must meet certain criteria to be accepted as medically, economically, and legally justified. The medical and economic justification for such tests is recognized by all concerned with controlling the excessive costs and human suffering associated with overexertion strain/sprain injury and illness in industry. The legal basis for such tests is not well established, and will not exist until a documented history of success or failure is developed in the courts for different types of tests.

It is hoped that as various tests are developed by medical departments, the criteria stated in the first part of this section will be of assistance. Strength testing and aerobic capacity testing have been implemented as part of medical examinations in a number of large industries as experimental medical procedures. Further studies are needed to validate and refine the necessary procedures.

TRAINING OF WORKERS

Training for safety in MMH has been in practice in several European countries since the Second World War. A pioneer in this field T. McClurg Anderson (The Institute of Kinetics, Glasgow) advanced the concept of "human kinetics" in the avoidance of unnecessary stress. It was widely adopted by a number of government departments and industries in the United Kingdom and forms the basis for industrial training courses run by the Royal Society for the Prevention of Accidents. Comparable modified courses are held for recruits in many industries and instructors' courses are run by organizations such as the British Safety Council. The Back Pain Association has recently published an instructors' manual, "Lifting in Industry." In France, the Institut Nationale de Recherche et de Securitie publishes "Gestes et postures de securitie dans le travail"; and similar courses are offered throughout Europe and Scandinavia.

The importance of training in manual materials handling in reducing hazard is generally accepted. The lacking ingredient is largely a definition of what the training should be and how this early experience can be given to a new worker without harm. The value of any training program is open to question as there appear to have been no controlled studies showing a consequent drop in the MMH accident rate or the back injury rate. Yet so long as it is a legal duty for employers to provide such training or for as long as the employer is liable to a claim of negligence for failing to train workers in safe methods of MMH, the practice is likely to continue despite the lack of evidence to support it. Meanwhile, it may be worth considering what improvements can be made to existing training techniques.

Training Aims

The aims of training for safety in MMH should be:

1. to make the trainees aware of the dangers of careless and unskilled MMH;
2. to show them how to avoid unnecessary stress and
3. to teach them individually to be aware of what they can handle safely.

Instructors must be well versed in the sciences basic to MMH and in Safety Engineering, and be practically experienced and skilled in all types of manual handling. The content of the courses should be suited to the educational background of the trainees. It is important not to underestimate people's practical intelligence and understanding.

The course should cover the following aspects:

1. The risks to health of unskilled MMH: This should be rooted in local experience and the MMH accident pattern of the organization concerned;

2. The basic physics of MMH: Every MMH worker should possess at least a subjective understanding which can be acquired using simple models (levers, beam-balances, pulleys, etc.) to illustrate:

   a. the principles of levers;
   b. the difference between the force needed to resist gravitational force on a load and the work needed to raise it;
   c. the work needed to move a load horizontally;
   d. the work needed to change the direction of motion;
   e. momentum and kinetic energy;
   f. Newton's 3rd Law of Motion.

3. The effects of MMH on the body: The basic functional anatomy of the spine and the muscles and joints of the trunk and limbs is easily taught to trainees in terms of their practical experience, and with reference to basic physics. It is easy to demonstrate muscular activity while muscles are being stretched or lengthened isometrically; how the rib cage is constrained by pushing and carrying; how the shoulder, abdominal and back muscles contribute to lifting. The increase in intrathoracic and intra-abdominal pressures during MMH is not difficult to understand because of the familiarity of breath-holding when making an effort.

4. Individual awareness of the body's strengths and weaknesses: The first practical lesson in MMH which all trainees must learn is how much they can handle comfortably; and where, in relation to their bodies, their strengths and weaknesses lie.

5. How to avoid the unexpected: There is a need to recognize the physical factors which might contribute to an accident, and eliminate them. For example:

   a. is the load free to move and not stuck?
   b. is it a weight that is comfortable to handle alone or should help be sought?
   c. are lifting aids available?
   d. has the load proper handles to grasp or can they be provided?
   e. is protective clothing indicated?
   f. is the area for MMH clear of obstruction?
   g. is the floor clean, dry and non-slip?
   h. is the area for setting the loads down clear?

6. Handling Skill: The actual handling tasks chosen for teaching purposes should cover a range of materials but the emphasis should be on the actual materials handled by the organization concerned. There are a number of points of general application which should be taught. Skill depends on:

   a. preparation to avoid being caught unaware,
   b. being able to recognize what can be handled comfortably without help,
   c. keeping the center of mass of the load close to the body when lifting,
   d. not twisting or bending sideways,
   e. using the legs to get close to the load and to make use of the body weight and the kinetic energy of the body and load,
   f. timing for smooth MMH.

7. Handling Aids: Handling aids are available for most material handling tasks. Often, they can be improvised if they do not exist. One problem here is encouraging their use, especially with unpaced or incentive jobs.

It is not enough to teach the theoretical aspects of safety in MMH and demonstrate the practical points by slides or films. Every trainee must be practically involved from the start: in the theoretical teaching of basic physics and functional anatomy; in learning how to recognize the loads that can be handled without undue sense of effort, and where in relation to the body MMH is easiest; and in acquiring the skills of safer and easier MMH. Classes cannot be large or the element of personal involvement is missing.

It is not enough to teach only in a classroom because the lessons must be applied on site. There is another danger in teaching only in a classroom and that is that many of the older (or longer employed) workers and supervisors have not been taught safe MMH techniques. If the instructors are never seen on site, the trainees quickly forget and go back to their old habits.

Many of the instructors of the past (and much of the published teaching material) have tended to rely on a dogmatic style of instruction; and sets of 'rules' for safe lifting are common. The drawback is that literal application of some of these rules has led to quite unsafe lifting practices. For example, to insist on the rule "Lift with the knees" is not well founded. In many people the quadriceps femoris muscle is just not strong enough. Moreover, this could lead to lifting at arm's length in front of the knees, thus creating more stress on the spine than the straight-legged stoop posture. Any rules used as memory aids should at least teach a basic aim or principle. What matters is that the trainee is led to a proper understanding of the problem and not merely expected to remember a set of catch-phrases.

CHAPTER 7

ENGINEERING CONTROLS

There are more hazards in manual materials handling than overexertion of the musculoskeletal or cardiovascular systems. Discrete mechanical hazards such as slips, falls and dropping of objects handled with subsequent damage or injury are important - so too are high and low temperature environments which can modify overall bodily response to the exertion of MMH. This chapter reviews these "other" hazards and suggests control methods and design criteria.

Manual materials handling is not a job done in isolation; rather it is part of the overall system by which industry handles and transports materials. Materials handling as a whole represents a large part of industry's costs with an average of 50 tons of materials moved for each ton of product produced. Hence materials handling systems design has emerged as a discipline with its own expertise and procedures. In order to aid the human in his/her role as materials handler it is important to realize the materials handling alternatives available, evaluate the alternatives available and choose the one which is optimum with respect to all criteria. The criteria include performance, cost and maintenance as well as safety. Many of the alternatives to manual materials handling have their own hazards so that this chapter classifies and reviews the methods available to avoid the introduction of substitute hazards into the workplace.

THE MECHANICAL ENVIRONMENT

The chief factors to be considered in designing the mechanical environment are the design of the container itself and the 'couplings' which transmit the container forces through the body to the floor or other working surface. The container itself affects safety directly through its weight and size (biomechanical stresses) and indirectly through the limitations it imposes on methods of holding and carrying it. The human/container coupling affects the ability to exert forces on the object, to maintain grip and to exercise control - all vital to safe handling. The human/work-surface coupling is important for maintaining stability and preventing the initiation of trips, slips and falls.

Container Design

From biomechanical considerations, containers should be as small as possible. In particular every biomechanical model or formula shows that $L5/S_1$ disc pressure is minimized when the center of gravity of the container is as close to the spinal column as possible (e.g., Tichauer, 1971; 1978; Ayoub, et al., 1978) as discussed in Chapter 3. Compactness also allows a load lifted from the floor to move between the worker's legs, decreasing spinal disc pressure.

Any factors which decrease the predictability of the container's response to applied forces will contribute to human error in manual handling. Examples are loads with an unexpected center of gravity (perhaps offset towards one face of the container) or those with a shifting center of gravity. Baffles, dividers or packing should be used to keep the center of gravity in a constant position.

The shape and size of the container are affected by anthropometric dimensions of the work as well as biomechanical considerations. The method of lifting and/or carriage determines the body posture adopted and thus the critical dimensions for safe handling.

For narrow containers one posture adopted is carriage by one hand at the side of the body, as with a suitcase. Containers carried in this way should be as narrow as possible as the maximum acceptable weight is directly related to container width. McConville and Hertzberg (1966) showed that for male military personnel:

$$\text{Maximum Acceptable Weight (kg)} = 35.52 - [0.169 \times \text{Width (cm)}]$$

With weights carried in one hand in this way an equal and opposite torque about the center line of the body is required for lateral balance. This contributes to the spinal stress so that it is usually preferable to carry two lighter containers, one in each hand, for improved balance.

For containers carried at the side of the body the main anthropometric requirement is that the arm can be fully extended downwards so that there are no unnecessary static tensions in the arm muscles. Maximum height to handle center, if the container is to be carried at arm's length, would be 72.5 cm for a 5th percentile (short) male and 65 cm for a 5th percentile female.

For containers carried in front of the body, it is usual to grip the container on each side, either along the base or along the forward edge, and pull the container against the frontal surface of the trunk, thereby supporting part of the weight with body/

container friction (assuming the material is not caustic or hot) thus relieving the static forces in the arm and shoulder muscles. There are no studies on the effect of hand position on this carrying task, and therefore, no recommendations on handle position are possible. It is possible to set limits on container size for this mode of carriage from anthropometric considerations. For the general population, if the forward edge is to be reached the length in the fore- and aft direction should not exceed 71 cm (males) or 65 cm (females). To prevent interference with forward vision, the maximum height of the container above handle position should be 82.5 cm (males) and 80 cm (females). If handles are not placed so that the whole container is above hip height with elbows extended, then interference with the legs will result during walking.

In general, handles should be placed above the container center of gravity for ease of container control but this may not be possible with bulky containers which would then interfere with leg movement. Kellerman and Van Wely (1961) in evaluating different shaped boxes to carry a constant (17.5 kg) weight of flower bulbs found both subjective preference and physiological evidence of the superiority of a wide, shallow container. Their optimum 100 x 30 x 12 cm deep container allowed the worker to carry it at arm's length without interfering with the legs during walking. A compact container is recommended but if deep ones are used it is suggested that handles be above the center of gravity for lifting from floor to table height to reduce stooping, and at or below the center of gravity for carrying or lifting above table height to reduce leg interference.

Human/Container Coupling Design

The handle or hand-hold is the coupling between the container and the worker and should be designed with the worker's hand in mind. The importance of proper hand/container couplings cannot be overstressed. They have a large effect on both the maximum force a worker can exert on a container and on the energy expenditure in manual materials handling tasks. Aside from manual materials handling injuries, Rigby (1973) shows that lack of handles is a prime reason for people dropping products, with resultant product damage. Handle design is usually rather poor in practice. Woodson (1971) notes that off-the-shelf handles appear to be "designed as decorative appointments" rather then "designed to fit the hand". The major problems Woodson reports are insufficient hand clearance, sharp edges which can cut into a worker's hand and too small a handle diameter.

Postures of the hand with respect to grasped objects have been classified by Napier (1956) into

1. A hook grip in which the fingers are flexed around the object and the thumb is not used for gripping.

2. A power grip in which the object is clamped between the partly flexed fingers and palm with the thumb opposing the grip and lying along the plane of the palm, and

3. A precision grip in which the object is pinched between the flexor aspects of the fingers and opposing thumb.

Most handles, hand-holds or gripping aids on containers force the worker to use a hook grip (the least effective) or a power grip. This latter gives a good gripping force and allows a large surface area of hand to be used but it is inefficient if accurate control of the container is needed. Frequently, however, the weight of a container will not allow a precision grip to be used.

The other main consideration in handle design is the nature of the forces that are to be transmitted through the handle to the container. Figure 7.1 shows the forces and torques associated with handle use. Most studies of handle design have assumed that the best size, shape and texture of the handle can generalize from one use to another: their results do not show close enough agreement to support this contention.

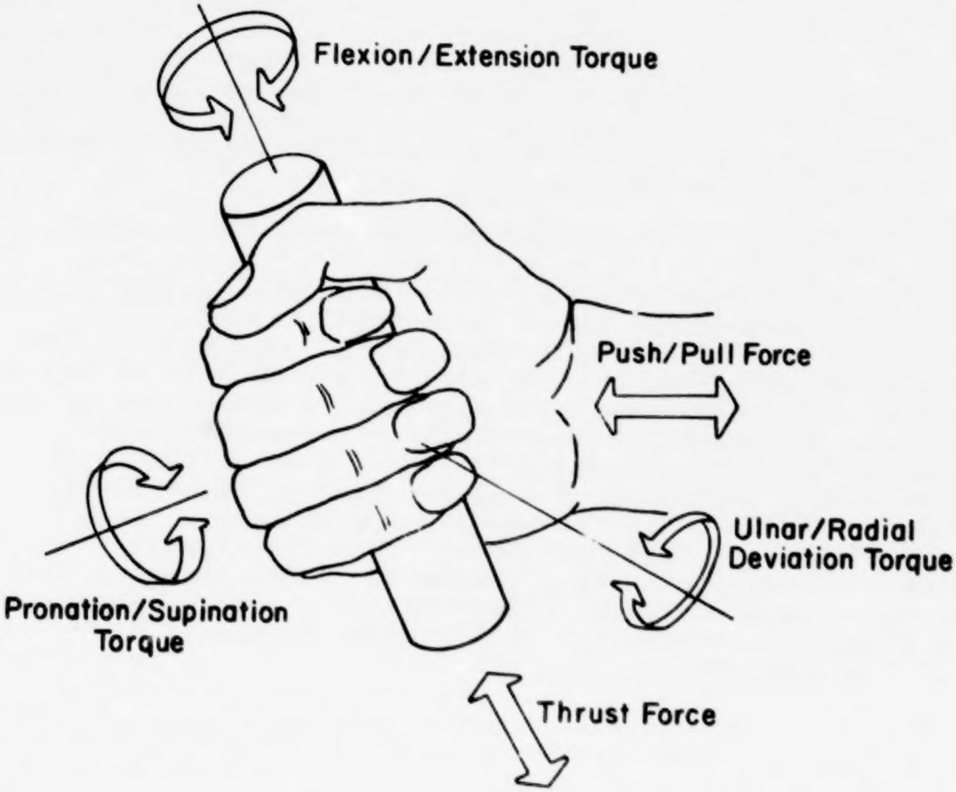


Figure 7.1: Hand Forces and Torques on Handles

One major variable has been handle diameter, whose effect has been measured for different forces and torques and using different criteria. Pheasant and O'Neill (1975) measured flexion/extension torques and found the larger the handle the better, at least up to 70 mm diameter although maximum shear force at the handle surface was greatest for a diameter of 30-50 mm. Thrust forces peaked at about 44 mm diameter. Flexion/extension torque was maximized using rough knurled surfaces in place of smooth cylindrical handles. There was no effect of a wide variety of handle shapes on maximum torques when the effect of diameter was eliminated.

The pronation/supination torque was measured as a function of handle diameter by Saran (1973), who found that a 2.5 cm diameter handle was preferred over either a 1.9 or a 3.2 cm handle. There were no differences between handle diameters in terms of electromyographic (EMG) activity of the muscle groups involved in the task.

Tasks requiring the production of a push/pull force have been used to evaluate handle diameter in a number of studies. This is perhaps the most relevant type of task for designing container handles. Ayoub and LoPresti (1971) found a relatively flat optimum between about 25 mm and 64 mm diameter when EMG was measured. However grip forces were optimum for a diameter of 38 mm. Khalil (1973) measured EMG activity for three diameters of cylindrical handle, (3.5, 5 and 7 cm) plus an elliptical handle 5 cm long x 3.2 cm wide and a 5 cm diameter sphere. Of all these handles the 3.2 cm diameter handle was best.

Two unpublished studies both requiring a pull force (Sanderson, 1976; Salvaterra and Chiusano, 1977) have tested cylindrical handles in different tasks. The former used a holding task and handles from 1 to 2.5 cm and found an optimum at 1.9 cm. The latter used both a subjective scale and a change in grip strength following a one minute holding of a 15 kg container to evaluate handles from 1 to 5 cm. Optima were found in each case at the center of the range, 1.9 cm and 3.8 cm respectively.

Other recommendations can be made based on different criteria. If the hand is to fit the handle with no overlap of fingers and thumb then Garret's (1971) anthropometric data would suggest 41 mm as a maximum diameter for a 5th percentile male without gloves. Similarly, guidebook recommendations in human engineering recommend diameters as follows (Rigby, 1973):

Weight of Item	Miminum Diameter
15 lb.	6 mm
15-20 lb.	13 mm
20-40 lb.	19 mm
40 lb.	25 mm

These values are quoted without evidence as to their efficacy.

Design Recommendations for Handles

For final recommendations on handle diameter, there is little agreement in the literature, although diameters from 25 to 38 mm receive more support than most and thus must, reluctantly, be recommended. The elimination of sharp edges, seams, ribbing, and corners appears to be an equally important criteria. The handle should be textured to provide maximum gripping force, particularly if other than a pull force is to be exerted. The shape of the handle is better cylindrical than molded to the contours of the hand. Tichauer (1966, 1971, 1978) demonstrates the limitations of such form-fitting handles. It is almost impossible to design finger grooves into a handle in such a way that they fit a large percentage of the population. Thus any set of finger grooves will impair performance for those workers not perfectly fitted.

Handle or hand-hold width should be at least 11.5 cm, with 5 cm clearance all around the handle to accommodate a 95th percentile hand. If use with gloves is anticipated, at least 2.5 cm should be added to these dimensions.

Worker/Floor Surface Coupling

The worker/working surface coupling has been cited as a causative factor in a large percentage of accidents, particularly trips and falls (Safety Science, 1977). The major types of accidents of this type are:

1. slip (loss of traction on work surface)
2. trip (movement of lower body arrested)
3. mis-step (putting foot down where there is no support)

These accident patterns account for almost three quarters of work-surface related accidents. The major mediating variable in this type of accident is the coefficient of friction between the shoe sole and the working surface. Pfauth and Miller (1976) review shoe/working surface friction and find it affected by:

1. work surface material (wood, concrete, steel, tile, etc.; Irvine, 1967; Kroemer, 1971, 1974; Sigler, 1943).
2. surface coating (e.g., waxes can both increase and decrease friction; Braun and Roemer, 1974).
3. floor condition (clean or dirty; wet, dry or greasy; e.g., Irvine, 1967; Kroemer, 1971, 1974; Sigler, 1943).

4. floor angle (Harper, Warlow & Clark, 1961; found higher coefficients of friction were needed on increasingly steeper slopes).

5. shoe sole/heel composition and contact area (rubber soles and certain synthetic soles are better than leather under dry conditions, but differences reduce or even reverse under wet conditions; Irvine, 1967; Kroemer, 1971, 1974; Sigler, 1943; Safety Sciences, 1977).

6. The style of shoe (Harper, Warlow & Clarke, 1961, found that shoes with high or narrow heels are the most hazardous). In a related area Tichauer (1966) found potential problems of biomechanical stresses from lifting in higher heels.

The general recommendation is to adjust shoes and working surfaces to give a coefficient of static friction of at least 0.4 and preferably 0.5. Unnoticed changes in surface friction are implicated in many accidents. Going from a less slippery floor to a more slippery one produces slips, the opposite change produces trips and mis-steps. These unnoticed changes can be reduced by:

1. ensuring that different surface materials or coatings have transition zones between them.

2. clearly marking any surface friction change.

3. using good housekeeping procedures to reduce transient changes in surface friction such as spills, worn spots, loose or irregular floors.

These recommendations are of particular importance in manual materials handling where any handling other than direct lifting involves horizontal inertial forces transmitted from the container to the body. Such forces require increased frictional forces to prevent foot slippage. The carriage of weights also affects the body's learned reflexes for recovering from a slip or trip both by changing the normal weight distribution of the body and by preventing the arms from being used to regain balance or recover from the fall. Finally, if a fall does occur, the container becomes another moving mass in close proximity to the falling operator, with potential for both crushing and puncturing the body.

THE VISUAL ENVIRONMENT

While manual materials handling operations rarely demand the fine visual discrimination of delicate assembly work, they do require control of the visual environment for optimum performance and safety.

The total amount of light needed is easier to specify than the type of light. The task of manual materials handling involves vision of the container, the workplace around the container and the surface on which the operator stands. Following the IES Code for Interior Lighting, an illuminance of 150 lux in each of these areas is a recommended minimum.

Type of lighting can have a large effect on visual performance, particularly in the areas of depth perception and surface texture perception. The aim in both of these areas is to provide sufficient visual contrast for safe operation. Contrast, which depends on the difference in light reflected from two surfaces, can be controlled either by differential illumination or by differing reflectance. Differential illumination should apply to stairs or changes in walking surface such as shoe/surface friction changes. Low, angled illumination is recommended for enhancing surface texture to warn operators of changes in shoe/surface friction. Depth perception errors are usually controlled by changing the reflectance of the container and task to provide additional contrast. Color contrast can also be used in critical areas such as edges of steps, loading docks and ramps where the consequences of misperception are severe.

The American National Standard Z53.1, 1967, Safety Color Code recommends the Yellow be used for marking hazards that may result in accidents from slipping, falling, striking, etc. Yellow indicates flammable liquid storage cabinets, materials handling equipment, radiation hazard areas, etc. Often black stripes or a checkerboard pattern can be used with the yellow color.

In situations where the operator may be unfamiliar with a particular container, or where a variety of containers are handled, appropriate labels and markings should be put on the container. These should be designed to ensure that the best handling position is adopted and that the appropriate force is applied. All lettering should be of a uniform style (e.g., MIL STD 33558).

Labelling should indicate handhold positions, cautions against single person lifting if the load is heavy, or a note of caution if its center of gravity is not near the center of the container, or if its center of gravity is likely to shift. The center of gravity and total weight warnings are particularly important with modern packaging methods, where the size of the container may bear very little relationship to its weight and dynamic characteristics.

Labels should be printed on all sides of a container, facing in at least two directions so that they are visible to the operator at all times. Labelling should aim for brevity and simplicity if it is to be used and understood on the maximum number of occasions.

THE THERMAL ENVIRONMENT

Early studies on mine workers showed a relationship between environmental (air) temperature and accident rates (Vernon and Rusher, 1920).

A number of studies (Edholm, 1967) have confirmed increased accident rates away from the comfort zone (18°C to 21°C, 65°F to 70°F) and a greater effect of temperature for older workers. It is thus particularly important to ensure that thermal stress does not contribute to manual materials handling safety problems.

Cold environments are not usually a problem in MMH safety; the strenuous nature of many of the MMH jobs gives a rate of metabolic heat production sufficient to prevent hypothermia. However, colder environments can lead to reduced dexterity (e.g., Wentzel, 1968) which could increase human error in MMH. Also colder temperatures can motivate workers to wear protective clothing, particularly at the extremities. Powell, et al., (1971) found decreased accidents at lower environmental temperatures in a warehousing operation, much of the effect due to the operators wearing their safety gloves in colder weather for reasons of thermal comfort.

In hot environments the added metabolic heat produced inside the body by MMH work can result in greater risk of overstrain and heat illnesses. To prevent excessive exposure to heat, an assessment must first be made of whether or not a heat problem exists. Currently, the most accepted method for determining heat load is decribed in the Threshold Limit Value (TLV) booklet of the American Conference of Governmental Industrial Hygienists (ACGIH, 1980). Figure 7.2 shows the lines of permissible exposure to work in hot environments as developed by Dukes-Dobos and Henschel (Dukes-Dobos, 1976) which was adopted by the ACGIH as the TLV for heat stress. The values given apply to acclimated workers who are physically fit.

Various measures are possible for the alleviation of the heat stress problem. All seek to reduce heat storage by the body, either by limiting input heat load from the environment, by limiting metabolic heat generation, or by limiting exposure duration. In practice this can mean air conditioning, radiant heat shielding, forced air movement, clothing design to minimize heat absorption and maximize evaporative cooling, and finally the design of work-rest schedules to prevent body temperature from increasing during the work shift.

Other methods of estimating metabolic costs for manual materials handling tasks are available (Givoni and Goldman, 1971; Garg, et al., 1978).

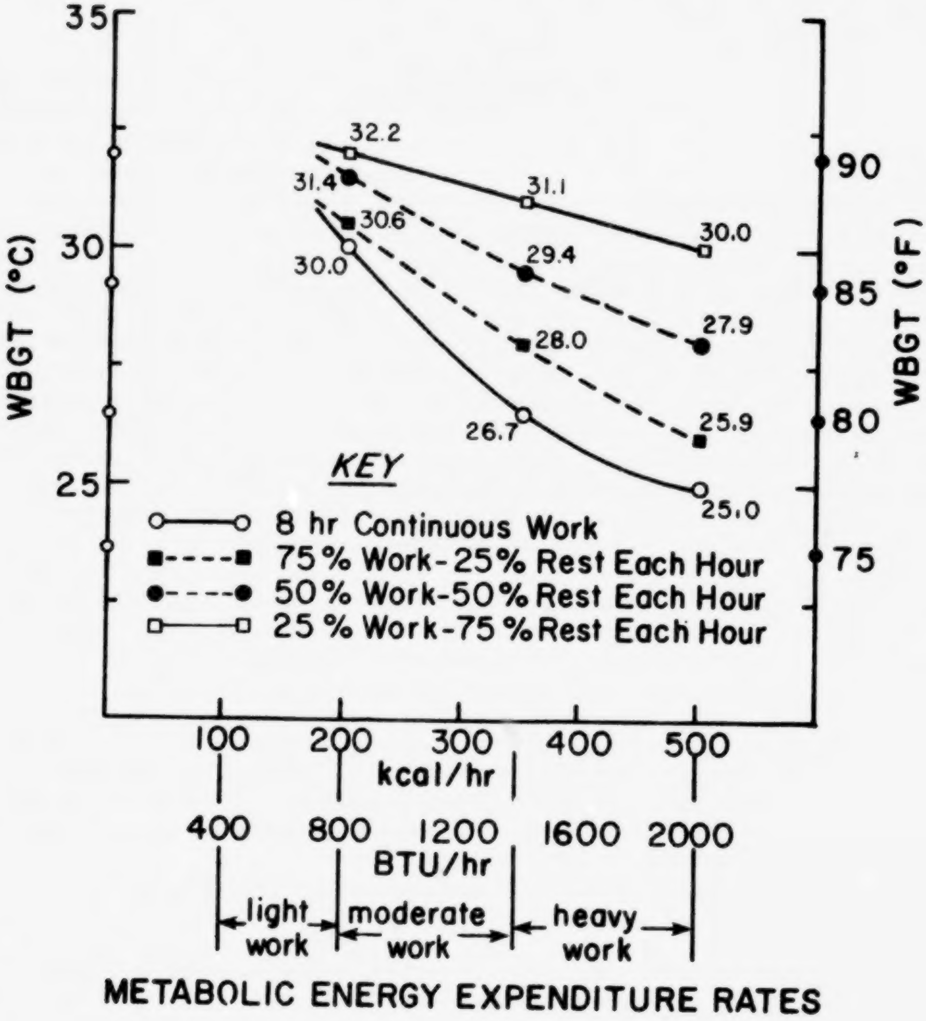


Figure 7.2: Lines of Permissible Exposure to Work in Hot Environments (Dukes-Dobos, 1976)

These can be combined with detailed treatments of the physics of heat transfer between human beings and their working environment (Berenson and Robertson, 1973) so that a detailed analysis of human thermal load can be made (Givoni and Goldman, 1971, 1973). These allow the effects of changes in environment, clothing and workload to be predicted and engineering controls to be installed in advance.

MATERIALS HANDLING SYSTEM ALTERNATIVES

The materials handling function is ubiquitous throughout industry occurring in at least seven areas.

1. Transportation of Raw Materials. Each delivery of materials to the plant whether by road, air, rail or water requires material moving equipment and people. Often such transportation of raw material is performed by outside carriers over which the plant management has little control. Still, their interaction with the manufacturing process must be recognized as important.

2. Receiving. Unloading the material from the transporting vehicle and moving the materials to their assigned places constitutes materials handling. Furthermore, inspection for weight, quality, quantity, etc., generally involves handling operations. Often, the handling itself takes more time than the inspection or storing action.

3. In-process Handling. The handling of material within the plant and particularly between work stations constitutes major materials handling problems with respect to effort, cost, and danger of accidents. Pieces may be moved many times in manufacturing plants either as single elements or combined with others in subsystems or units. Storage of in-process parts between operations is a very critical area of materials handling.

4. Handling at the Work Place. This is one of the most overlooked but costly operations in materials handling. It usually involves manual movement of material among fixtures and jigs, into and from machines, and the disposal of by-products and wastes. This is a phase in materials handling which contributes significantly to injuries and accidents.

5. Handling of Wastes and By-products. Rejects, wastes and by-products produced in the manufacturing process, or used packaging material, must be moved and disposed. This may involve sorting of materials that can be used again or recycled, and of those materials that are discarded. This is also an often overlooked aspect of materials handling.

6. Warehousing. The storing, stocking, order picking, assembly of orders, packing and movement out of the warehouse are material handling operations.

7. Distribution. The transportation of the finished or processed goods and materials is the last part of materials handling in the manufacturing cycle. This usually involves, like the transportation of raw materials, road, rail, air or water vehicles, and is often done by outside carriers.

Materials handling systems can be classified in many ways by their function and purpose. The International Material Management Society and the ASME have adopted a decimal classification system with nine major classes. The four most useful classes within a factory are:

1.000 Conveyors
2.000 Cranes and hoists
3.000 Positioning equipment
and 4.00 Industrial vehicles

Positioning equipment is used to transfer material from workplace to materials handling equipment or vice versa. It includes manipulators, dumpers, up-enders, positioning tables, lifts, jacks and transfer machines. As such positioning equipment provides an alternative to the unaided human operator at the workstation itself where many manual materials handling problems occur.

At the workplace simple job aids can often facilitate materials handling tasks. Examples are:

1. Hooks. The worker should be trained in the use of hand or packing hooks so that they will not glance off hard objects. If the hook is carried in the belt, the point must be covered.

2. Bars. The major hazard in the use of a crow bar is that it may slip. The point or edge should have a good "bite".

3. Rollers. Rollers are often used to move heavy and bulky objects. The principal hazard is that fingers or toes may be pinched or crushed between a roller and the floor.

4. Jacks. All jacks should be marked to indicate the safe load they can support. The surface onto which a jack is placed must be level and clean and be sturdy enough to support the load. After the load is raised, substantial horses or blocking should be placed under it for support. Workmen using jacks should wear safety shoes and instep guard protection because handles may slip, or parts may fall.

5. Platforms. Platforms are useful for loading and unloading, provided that the load is maintained at a convenient height for lifting and handling.

6. Trestles. These and other supports may be used for maneuvering long loads on the point of balance, or for readjusting the grip or carrying posture.

The other three types of materials handling equipment are used essentially between workstations. Their characteristics, functions and uses have been well summarized by Apple (1971) as follows.

Conveyors

These gravity or power devices are commonly used for moving uniform loads continuously from point to point over fixed paths where the primary function is movement.

1. Common examples include:
    - a. roller conveyors,
    - b. belt conveyors,
    - c. screw conveyors,
    - d. chutes,
    - e. monorails, and
    - f. trolley conveyors.
2. Conveyors are generally useful when:
    - a. loads are uniform,
    - b. materials move continuously,
    - c. routes do not vary,
    - d. loads are constant,
    - e. movement rate is relatively fixed,
    - f. conveyors can bypass cross traffic,
    - g. the path to be followed is fixed, and
    - h. movement is from one point to another.

Cranes and Hoists

These overhead devices are usually utilized to move varying loads intermittently between points within an area fixed by the supporting and guiding rails, where the primary function is transferring.

1. Common examples include:
    - a. overhead traveling cranes,
    - b. gantry cranes,
    - c. jib cranes,
    - d. hoists, and
    - e. stacker cranes.
2. Cranes and hoists are most commonly used when:
    - a. movement is within a fixed area,
    - b. moves are intermittent,
    - c. loads vary in size and weight,
    - d. cross traffic will interfere with conveyors, and
    - e. loads handled are not uniform.

Industrial Trucks

These hand or powered vehicles (nonhighway) are used for movement of mixed or uniform loads intermittently over varying paths which have suitable running surfaces and clearances and where the primary function is maneuvering or transporting.

1. Common examples include:
   a. forklift trucks,
   b. platform trucks,
   c. two-wheel hand trucks,
   d. tractor-trailer trains, and
   e. hand stackers.

2. Industrial trucks are generally used when:
   a. materials are moved intermittently,
   b. movement is over varying routes,
   c. loads are uniform or mixed in size and weight,
   d. cross traffic would prohibit conveyors,
   e. clearances and running surfaces are adequate and suitable,
   f. most of the operation consists of handling - lifting, maneuvering, stacking, and the like, and
   g. material can be put into unit loads.

Other classficatory schemes are possible, for example by the power requirements. At least three classes can be distinguished: Human Powered, Gravity Powered and Self-Powered. The total energy expended by the human operator is obviously highest for human powered systems with consequent increased probability of overstrain. But the total energy marshalled, and hence available for damage and injury, is greater for gravity- and self-powered systems.

The final classificatory variable is the coupling between the load and the materials handling system. Special-purpose attachments are available in profusion; forks, clamps, hooks, platforms and hoppers are all used across the other classifications of materials handling systems.

The aim in this classification is to enable the materials handling system designer to specify the function of the equipment rather than the equipment itself. This ensures that novel approaches to materials handling problems are not overlooked because of overfamiliarity with particular solutions.

POTENTIAL SAFETY AND ERGONOMIC PROBLEMS

Each of the major classes or materials handling equipment has problems of human/machine mismatch which are potential and actual sources of accident causing errors.

Conveyors

The major problem with conveyors, aside from purely mechanical entrapments, is that work is externally-paced. Human performance is inherently variable with successive cycle times on a repetitive task having a standard deviation of 10-20% of the mean time. Any attempt at external pacing of the operator gives rise to time-stress induced errors, even when the operator is paced at well below his/her mean unpaced performance. Murrell (1969) found that if missed components (errors) could only be tolerated at 0.5% of total production, then production rates had to be set 20-30% below optimum conveyor speed.

Not only must conveyor based systems be designed taking account cycle-to-cycle variability of one operator, but their operation must allow for operators of different abilities at each workstation. With typical between-operator ranges of 2:1 in cycle times this means that large numbers of operators will either be over-stressed or under-stressed in their work. One solution, as Sury (1965) shows is to increase the tolerance of the conveyor system for fast and slow cycles. He found that a time tolerance of 99% of the cycle time distribution for each operator was needed to remove the effects of too-rigid pacing. Buffer stocks between stations achieve the same effect.

Conveyors and their associated pacing have infamous effects on employee attitudes. For example Coetsier (1965) found that the imposition of pace was a more significant factor in negative attitudes than was the actual rate of work. Davies (1965) cites the use of a conveyor to enforce a particular work output as replacing the management functions of managers.

However, not all conveyors are paced. Many gravity or powered and free conveyors merely transport goods between workstations where the goods form a waiting line until operated upon by the worker. Another positive use of conveyors is the use of mobile conveyors or rollers to facilitate loading and unloading of trucks and containers.

Cranes and Hoists

Considering the dangers involved when heavy loads are suspended, cranes are among the most dangerous pieces of material handling equipment. For this reason, specific requirements must be met by all cranes. Overhead and gantry cranes must meet the design specifications of American National Standard B 30.2.0 (OSHA regulation 1910.179); all crawler, locomotive and truck cranes must meet the design specifications of American National Standard B301.5 (OSHA regulation 1910.180). Cranes installed before August 27, 1971, must be modified to conform to these requirements (see National Safety Council, Supervisor's Safety Manual).

1. The crane cab, and all controls, must be designed for good visibility, and safe operation. Sell (1977) showed how an integrated cab for an overhead crane could be designed.
2. Of course, no crane should be loaded beyond its rated load capacity, the load including the weight of all auxiliary handling devices such as hoist blocks, hooks, and slings.
3. Load hooks, chains, ropes, and the hoisting device itself must be clearly marked with the maximum allowable load.
4. Loads must not be carried over people, and may not be moved while a person is on the load or hook.
5. The operator must be thoroughly trained. He must not leave his position at the controls while the load is suspended.
6. Standard signals should be used between the crane operator and the signal man on the ground.

Most of the materials handling accidents investigated by Coleman, et al., (1978) were connected with falling, slipping, or bumping of the load. The major factors in such accidents were inadequate communications between the crane operator, the hitcher, and the signal man. Often the visibility from the cab was insufficient, the controls inadequate, and the overall design required tiring body positions. Simple ergonomics principles of control positions and directions of movement, workplace layout and visibility are readily available (e.g., McCormick, 1976; VanCott and Kinkade, 1972) and should be used in design or redesign.

Hoists and particularly air-balance hoists are useful at the workplace where heavy components can be moved with only small (control) forces having to be supplied by the human operator.

Industrial Trucks

Human factors and safety design weaknesses found by Coleman, et al., (1978) concerned missing or inadequate safety devices, lack of standardization in braking, reduced visibility, cramped driver compartments, seats not damping transmission of road impacts and vibrations, and not providing sufficient body support.

Hazards often encountered in the operation of powered and hand trucks include:

1. contact with the moving parts of the truck,
2. falling of the load, particularly at corners and on inclines,

3. rollover,
4. collision between the truck and other object,
5. the operator getting pinned between the truck and another object, and
6. the truck running up the heels of the walking operator.

Many of these hazards also apply to dollies and wheelbarrows. They can be reduced or eliminated by using the following guidelines.

1. All exposed handles should be equipped with knuckle guards so that the operator's hands cannot be jammed against external obstructions.

2. All wheels should be recessed or otherwise guarded.

3. All trucks should have brakes that apply automatically when the handle is either fully raised or fully lowered, or released.

4. Major features should be standardized, e.g., brake activation on powered trucks.

Fox (1971) found many instances of negative transfer between different vehicles with different positions and directions of controls. He also found critical incidents caused by errors in blind reaching for controls while the driver's vision was directed to the load rather than the controls.

5. All operators must be trained to follow safe practices, such as

   a. proper loading (i.e., so that the vehicle is balanced, that the load will not fall off, that vision is not obscured, etc.)
   b. leaving the truck facing the traffic
   c. maintaining safe speed
   d. backing loads down inclines to avoid front end tipping
   e. lowering the fork to floor level when not in use
   f. chocking wheels if parked on an incline.

Pertaining OSHA regulations are detailed under Part 1910, Subpart N. particularly section 1910.178. Two anonymous articles, "powered Hand Trucks," (July 1975 issue, National Safety News, 53-57), and "Industrial Trucks - Their Operations and Maintenance," (September 1975 issue, Industrial Engineering, 32-37) discuss many of the safety features and lists applicable safety standards and recommendations.

Fork-lift trucks have the dubious distinction of violating many human engineering principles and recommendations, and of having many accidents. Human engineering data and recommendations shoudl be made as the basis for design or purchase of a new fork-lift truck. In its operation, many mishaps can be avoided by using "safe practices" in training the new operator, in monitoring the operator's performance, and by enforcing safe practices by positive (reward) and negative (punitive) control measures (Lovested, 1977).

Again many of these problems can be alleviated by the intelligent application of ergonomics/human factors principles. The environment in which the industrial truck operates can have a large effect on its efficiency and safety. Drury and Dawson (1974) evaluated control performance of five powered fork trucks and found that considerable lateral room was required even to drive them consistently in a straight line. For drivers concentrating totally on vehicle control, an aisle width of 0.5 m greater than truck or load width was required. In more realistic situations where the operator must monitor the load stability, plan his/her course through a factory and be alert to avoid other traffic much greater clearances are needed.

For human powered vehicles, Drury, Barnes and Daniels (1975) found that large wheels gave easier handling and that, again, adequate clear aisle widths had to be provided. Handles should be about 1 meter above the floor for maximum force exertion. With any human powered vehicle flatness of floors is essential and special care must be taken to avoid sudden floor steps of even a few millimeters as they can cause large increases in the force necessary to push or pull the vehicle.

CHAPTER 8

RECOMMENDATIONS

This chapter outlines load limit recommendations for lifting tasks. Sections on how to identify a hazardous lifting job, how to interpret the guidelines and how to apply them to actual lifting situations are provided. In addition, brief summaries of Chapter 6, Administrative Controls and Chapter 7, Engineering Controls, are included.

It is intended that this chapter will provide the Industrial or Safety Engineer with an easy means to quickly scan the Guide, pick out important points and apply them to the appropriate situation. References to earlier chapters are made if a more thorough and detailed discussion of a topic is desired.

DEFINITION OF A LIFTING TASK

For the purpose of this Guide, a lifting task is considered to be the act of manually grasping and raising an object of definable size without mechanical aids (i.e., hoists, conveyors, block and tackle, etc.). The time duration of such an act is normally less than two seconds, and thus little sustained exertion is required (as opposed to holding or carrying activities). The lifting limits presented in this chapter do not apply to all kinds of lifts. They are intended to apply only for:

a. smooth lifting
b. two-handed, symmetric lifting in the saggital plane (directly in front of the body; no twisting during lift)
c. moderate width, e.g., 75 cm (30 in) or less
d. unrestricted lifting posture
e. good couplings (handles, shoes, floor surface)
f. favorable ambient environments.

It is assumed that other manual handling activities such as holding, carrying, pushing, pulling, etc., are minimal. When not engaged in lifting activities, the individual is assumed at rest. The assumed work force is physically fit and accustomed to physical labor.

The Guide does not include "safety factors" commonly used by engineers to assure that unpredicted conditions are accommodated.

LIFTING TASK VARIABLES

The primary task variables identified earlier in this Guide on the basis of epidemiology (Chapter 2), biomechanics (Chapter 3), physiology (Chapter 4) and psychophysics (Chapter 5) of lifting include:

1. Object weight (L) - measured in kilograms (pounds)
2. Horizontal location (H) - of the hands at origin of lift measured forward of the body centerline or midpoint between ankles (in centimeters or inches)
3. Vertical location (V) - of the hands at origin of lift measured from floor level in centimeters (inches)
4. Vertical travel distance (D) - from origin to destination of lift in centimeters (inches)
5. Frequency of lifting (F) - average number of lifts per minute
6. Duration or period - assumed to be occasional (less than one hour) or continuous (8 hours)

The latter two variables (lift frequency and period) are the most difficult to define and consequently measure and provide guidance. For the purpose of this Guide jobs will be grossly classified in three categories:

1. Infrequent - either occasional or continuous lifting less than once per 3 minutes
2. Occasional high frequency - lifting one or more times per 3 minutes for a period up to 1 hour
3. Continuous high frequency - lifting one or more times per $\underset{5}{3}$ minutes continuously for 8 hours.

Evidence presented in earlier chapters shows that for *infrequent lifting* a person's musculoskeletal strength (Chapter 5) and potential high stress to the back (Chapter 3) are the primary limitations to ability. As such, biomechanical variables are predominant in determining hazard. *Occasional high frequency lifting* results in psychophysical stress (Chapter 5) and possible muscle fatigue as the primary limitations. For *continuous, high frequency lifting* the primary limitations are based on cardiovascular capacity and metabolic endurance (Chapter 4).

Table 8.1 summarizes which task variables are emphasized by the four approaches examined in Chapters 2-5. A careful review of these approaches shows two important points. First, all of the task variables are highly interactive. In other words, the

Table 8.1: Emphasis on task variables by alternative approaches.

	Epidemiology (Ch. 2)	Biomechanics (Ch. 3)	Physiology (Ch. 4)	Psychophysics (Ch. 5)
Object Weight (L)	X	X	X	X
Horizontal Location (H)	X	X	X	X
Vertical Location (V)	X	X	X	X
Travel Distance (D)			X	X
Frequency of Lift (F)	X		X	X
Duration or Period (P)			X	

importance of object weight (for example) is highly dependent on where the weight is located (horizontally and vertically), how far it must be moved, and how frequently. Thus, none of these variables should be evaluated independently.

Secondly, the four approaches taken separately may lead to different conclusions. For example, metabolic criteria (Chapter 4) can lead one to believe lifting heavy loads infrequently is preferred to frequent lifting of lesser loads (due to the cost of moving the body). From a biomechanical or strength point of view, (Chapters 3, 5) object weight should be minimized regardless of frequency.

Another example has to do with object location. A person is generally strongest when lifting with the legs and back. Were strength the only criterion, (Chapter 5) one would favor leaving objects on the floor rather than on shelves. Of course, biomechanical low back compression (Chapter 3) and cardiovascular (Chapter 4) criteria would deem this least desirable.

CRITERIA FOR GUIDELINE

It is concluded, regardless of the approach taken to evaluate the physical stresses of lifting, that a large individual variability in risk of injury and lifting performance capability exists in the population today. This realization requires that the resulting controls be of both an engineering and administrative nature. In other words, there are some lifting situations which are so hazardous that only a few people could be expected to be capable of safely performing them. These conditions need to be modified to reduce stresses through job redesign. On the other hand, some lifting conditions may be safely tolerated by some people, but others, particularly weaker individuals, must be protected by an aggressive selection and training program. To specifically define these conditions two limits are provided based on epidemiological, biomechanical, physiological, and psychophysical criteria.

1. Maximum Permissible Limit (MPL)

   This limit is defined to best meet the four criteria:

   a. Musculoskeletal injury rates and severity rates have been shown to increase significantly in populations when work is performed above the MPL.

   b. Biomechanical compression forces on the L_5/S_1 disc are not tolerable over 650 kg (1430 lb) in most workers. This would result from conditions above the MPL.

   c. Metabolic rates would exceed 5.0 Kcal/minute for most individuals working above the MPL.

   d. Only about 25% of men and less than 1% of women workers have the muscle strengths to be capable of performing work above the MPL.

2. Action Limit (AL)

   The large variability in capacities between individuals in the population indicates the need for administrative controls when conditions exceed this limit based on:

   a. Musculoskeletal injury incidence and severity rates increase moderately in populations exposed to lifting conditions described by the AL.

b. A 350 kg (770 lb) compression force on the L_5/S_1 disc can be tolerated by most young, healthy workers. Such forces would be created by conditions described by the AL.

c. Metabolic rates would exceed 3.5 for most individuals working above the AL.

d. Over 75% of women and over 99% of men could lift loads described by the AL.

Thus, properly analyzed lifting tasks may be of 3 types:

1. those above the MPL should be viewed as unacceptable and require engineering controls
2. those between the AL and MPL are unacceptable without administrative or engineering controls
3. those below the AL are believed to represent nominal risk to most industrial workforces.

To illustrate this point, Figure 8.1 shows the three regions and boundaries defined for infrequent lifting ($F < .2$) from the floor ($V = 15$ cm [6 in]) to knuckle height ($D = 60$ cm [24 in]). Depending on the size of the object, in terms of horizontal hand location, the maximum weight which can be lifted can be determined

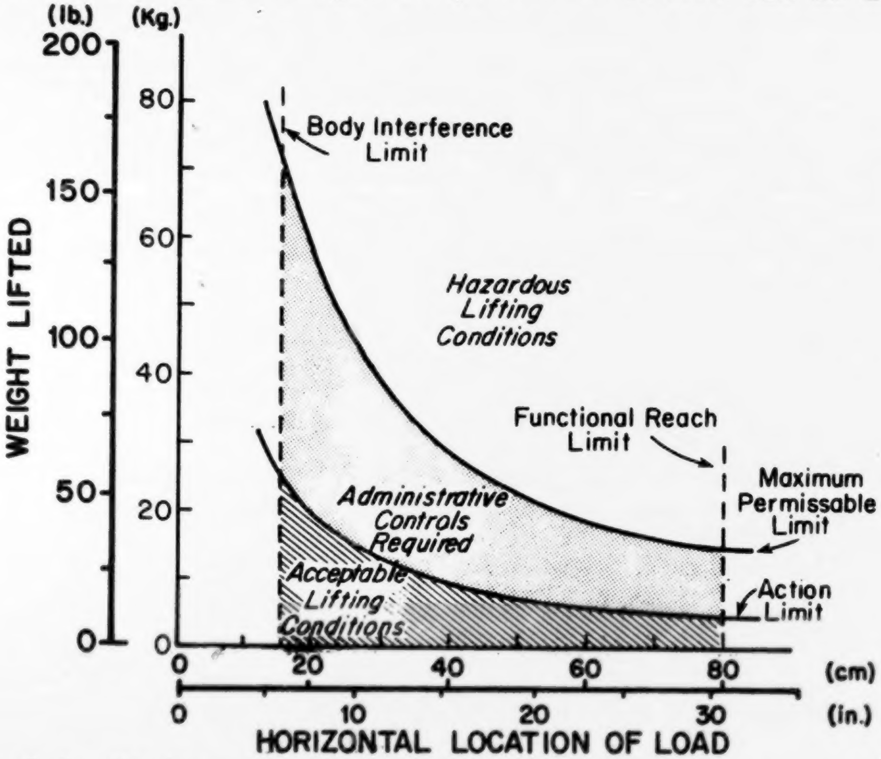


Figure 8.1: Maximum Weight versus Horizontal Location for Infrequent Lifts from Floor to Knuckle Height

GUIDELINE LIMITS

With the large number of task variables (5 in this case) which modify risk during lifting it is virtually impossible to provide a simple yet accurate procedure for evaluating all possible jobs. This problem is further complicated by the need to satisfy four separate criteria (epidemiological, biomechanical, physiological, and psychophysical). The following guideline is the simplest form known which best satisfies the four criteria.

In algebraic form:

$$AL\ (Kg) = 40(15/H)(1-.004|V-75|)(.7+7.5/D)(1-F/F_{max})\text{-metric units}$$

or

$$AL\ (lb) = 90(6/H)(1-.01|V-30|)(.7+3/D)(1-F/F_{max})\text{-U.S. Customary units}$$

$$MPL = 3\ (AL)$$

where H = horizontal location (centimeters or inches) forward of midpoint between ankles at origin of lift

V = vertical location (centimeters or inches) at origin of lift

D = vertical travel distance (centimeters or inches) between origin and destination of lift

F = average frequency of lift (lifts/minute)

F_{max} = maximum frequency which can be sustained (see Table 8.2)

For purposes of this Guide, these variables are assumed to have the following limits.

1. H is between 15 cm (6 in) and 80 cm (32 in). Objects cannot, in general, be closer than 15 cm (6 in) without interference with the body. Objects further than 80 cm (32 in) cannot be reached by many people.
2. V is assumed between 0 cm and 175 cm (70 in) representing the range of vertical reach for most people.
3. D is assumed between 25 cm (10 in) and (200-V) cm [(80-V) in]. For travel less than 25 cm, set D = 25.
4. F is assumed between .2 (one lift every 5 minutes) and F_{max} (see Table 8.2). For lifting less frequently than once per 5 minutes, set F = 0.

Table 8.2: F_{max} Table.

		AVERAGE VERTICAL LOCATION (cm)(in)	
		$V > 75$ (30) Standing	$V \leq 75$ (30) Stooped
PERIOD	1 hour	18	15
	8 hours	15	12

The above equations for the action limit (AL) and maximum permissable limit (MPL) represent a multiplicative factor weighting for each task variable. The first factor

$$H \text{ Factor} = (15/H)$$

represents the importance of the horizontal location (H). If H = 15 cm this factor is 1 and no adjustment for horizontal location is necessary. If H = 75 cm, this factor is 15/75 = .20 meaning the AL is reduced from 40 to 40(.20) = 8 kg.

The factor for vertical location involves the absolute deviation of V from 75 cm (approximate knuckle height). For V = 75, the V factor is

$$V \text{ Factor} = (1-.004|V-75|)$$

$$= (1-.004(0)) = 1$$

For V = 15,

$$V \text{ Factor} = (1-.004|15-75|)$$

$$= 1-.004(60) = .76$$

Likewise for V = 135,

$$V \text{ Factor} = (1-.004|135-75|)$$

$$= 1-.004(60) = .76$$

Likewise, the D factor ranges from 1 to .74 as D varies from 0 to 200 cm.

$$\text{D Factor} - (.7+7.5/D)$$

For D = 0 set D = 25 (the minimum allowed value), then

$$\text{D Factor} = (.7+7.5/25) = 1.0$$

For D = 200,

$$\text{D Factor} = (.7+7.5/200) = .74$$

The F factor is a bit more complicated. If the lifting originates below 75 centimeters (on the average $V \leq 75$) and is performed continuously throughout the day, $F_{max} = 12$ (as given in Table 8.2). If the observed frequency is 6 lifts per minute (F = 6) then,

$$\text{F Factor} = (1-F/F_{max})$$

$$= 1-6/12 = .5$$

The effective weight which can be lifted is thus halved due to frequency of lifting required.

Combining factors is illustrated for continuous lifting below knuckle height with average H = 20 cm, V = 40 cm, an average distance of D = 100 cm, at a rate of 6 lifts per minute; then

$$AL = 40\ (15/20)(1-.004|40-75|)(.7+7.5/100)(1-6/12)$$

$$= 40\ (.75)(.86)(.78)(.5) = 10\text{ kg.}$$

$$MPL = 30\text{ kg.}$$

The mechanics of this example would be exactly the same using the U.S. Customary form of the equation and the task variable limits given on page 120. The weight handled on the job could be compared directly with these values. Suppose the load was 35 kg (above the MPL). In this case, one "engineering control" might be to reduce the frequency of lifting from 6 per minute to 1 per minute (admittedly a drastic change). This would increase the frequency factor from .5 to .92 and consequently the

$$AL = 18.4\text{, and}$$

$$MPL = 55.2$$

Viewing the relative weights of each factor (.75)(.86)(.75)(.50) in this case allows a quick evaluation of the relative weights associated with changes in any factor. Frequency of lifting is the biggest discounting factor (.5) in this case and should receive first consideration.

Reducing frequency to 1 lift per minute would lower the stressfulness of the job to within the "administrative controls" region. In this case, 35 kg is between AL = 18.4 and MPL = 55.2. This should not preclude further "engineering controls". It is important to realize that the job still cannot be safely performed by most women or the majority of men. Further reductions in the frequency (factor = .92) would be ineffective since this factor can only increase to 1.0. The load probably cannot be brought appreciably closer to the body (H = 15 versus H = 20 cm).

The best engineering solution at this point would be to change the load weight. Halving the weight (from 35 kg to 18 kg) would be one solution to achieving a task within the capabilities of most people (18 kg is less than AL = 18.4 kg). An equally acceptable solution would be to increase the load to 100 or more kg and provide mechanical lifting aids thus precluding manual handling and relieving the person of lifting altogether.

JOB PHYSICAL STRESS EVALUATION

The purpose of the job physical demands evaluation is to identify, quantify and document the physical stresses associated with a given job. This section outlines how such an evaluation should be performed so that the guidance of the previous section may be applied.

Selection of Analysts

All job analyses should be performed by an individual who has experience in work measurement and who is thoroughly familiar with the plant and the jobs done in it. The analyst should know the prescribed methods of performing these jobs and should be aware of all tasks (including any irregularly occurring tasks) associated with the job.

Selection of Employees

Only experienced employees who routinely perform their work according to job descriptions and who work at a normal pace should be selected for measurement during the job evaluation. This will assure that the job description accurately describes the work performed.

Selection of Jobs

Jobs should be rank ordered by incidence and severity rates of musculoskeletal disorders. Jobs with the highest rank should be studied first. The primary source used to formulate this sort of job ranking should come from medical information (if available) such as:

- medical reports
- first aid reports
- OSHA 101 forms
- worker's compensation payments

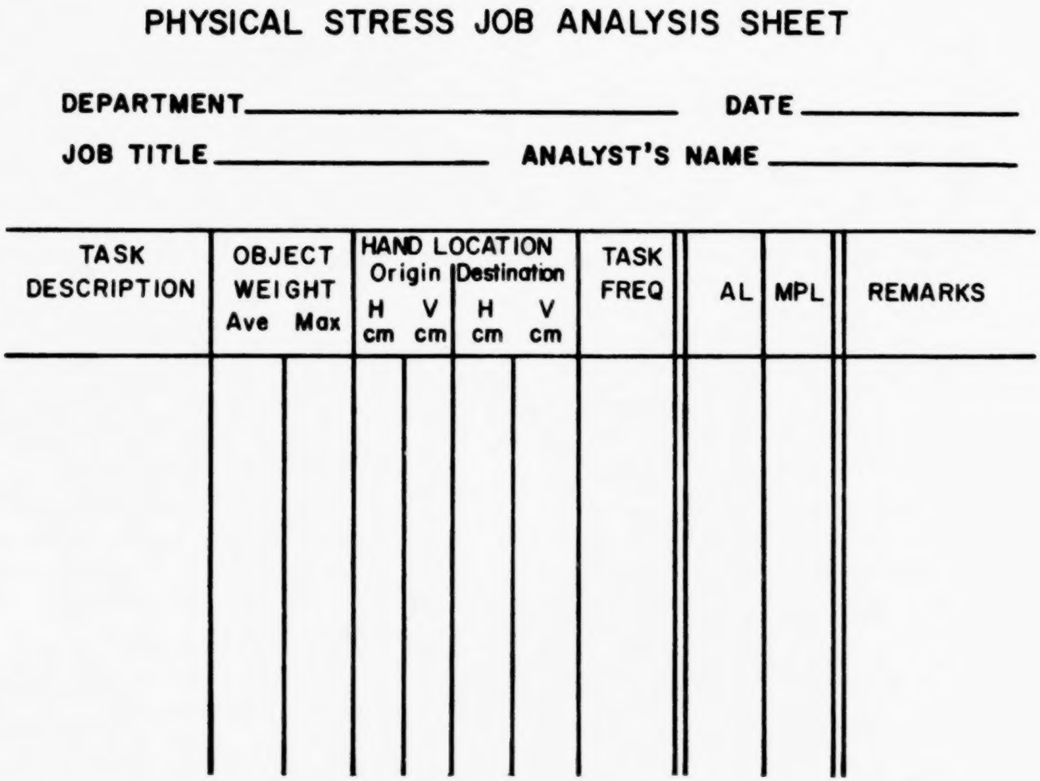
Things to look for on these reports include:

1. musculoskeletal injuries, particularly back injuries
   - overexertion
   - strains/sprains
   - contact injuries such as:
     - lacerations
     - bruises
     - abrasions
     - fractures
2. what job the injury occurred on so that a total for each job can be compiled
3. how much lost time was associated with each injury. In the absence of medical records, stressful jobs can be identified by information obtained from line supervisors or foremen for a particular job, such as:
   - is there a high turnover rate?
   - is there frequent absenteeism?
   - are there frequent sprain/strain complaints?

Analysis Procedures

All data collected should be organized on a "Physical Stress Job Analysis Sheet" (see Figure 8.2). The exact form is, of course, optional but it should include background and identification information for each job such as date, plant name, department, analyst's name and job title as well as the task descriptors to be measured. These are:

1. Weight of the object lifted - determined by direct weighing. If this varies from time to time, note the average and maximum weights.
2. The position of the load with respect to the body - this must be measured at both the starting and ending points of a lift in terms of horizontal and vertical location. The horizontal location from the body (H) is measured from the midpoint of the line joining the ankles to the midpoint at which the hands grasp the object while in the lifting position. The vertical component is



PHYSICAL STRESS JOB ANALYSIS SHEET

DEPARTMENT____________________ DATE __________

JOB TITLE_______________ ANALYST'S NAME ______________

TASK DESCRIPTION	OBJECT WEIGHT		HAND LOCATION				TASK FREQ	AL	MPL	REMARKS
			Origin		Destination					
	Ave	Max	H cm	V cm	H cm	V cm				

Figure 8.2: Example Coding Form.

determined by measuring the distance from the floor to the point at which the hands grasp the object. The coordinate system is illustrated in Figure 8.3.

These measures are repeated for the ending point of the lift (in the lifting position) and all four values are recorded on the job analysis sheet.

It these four values vary from task to task (e.g., stacking cartons on top of each other), the job must be separated into elements and each element evaluated. Examples later will suggest ways to handle such situations.

To be precise, the H value should be measured as described in item 2. However, a convenient rule of thumb is H = (W/2+15) cm or (W/2+6) in, where W = the distance of the load away from the body measured in the horizontal axis (fig. 8.3).

3. Frequency of lift - this should be recorded on the job analysis sheet in average lifts/min. for high frequency jobs. A separate frequency should be entered for each distinguishable job task.

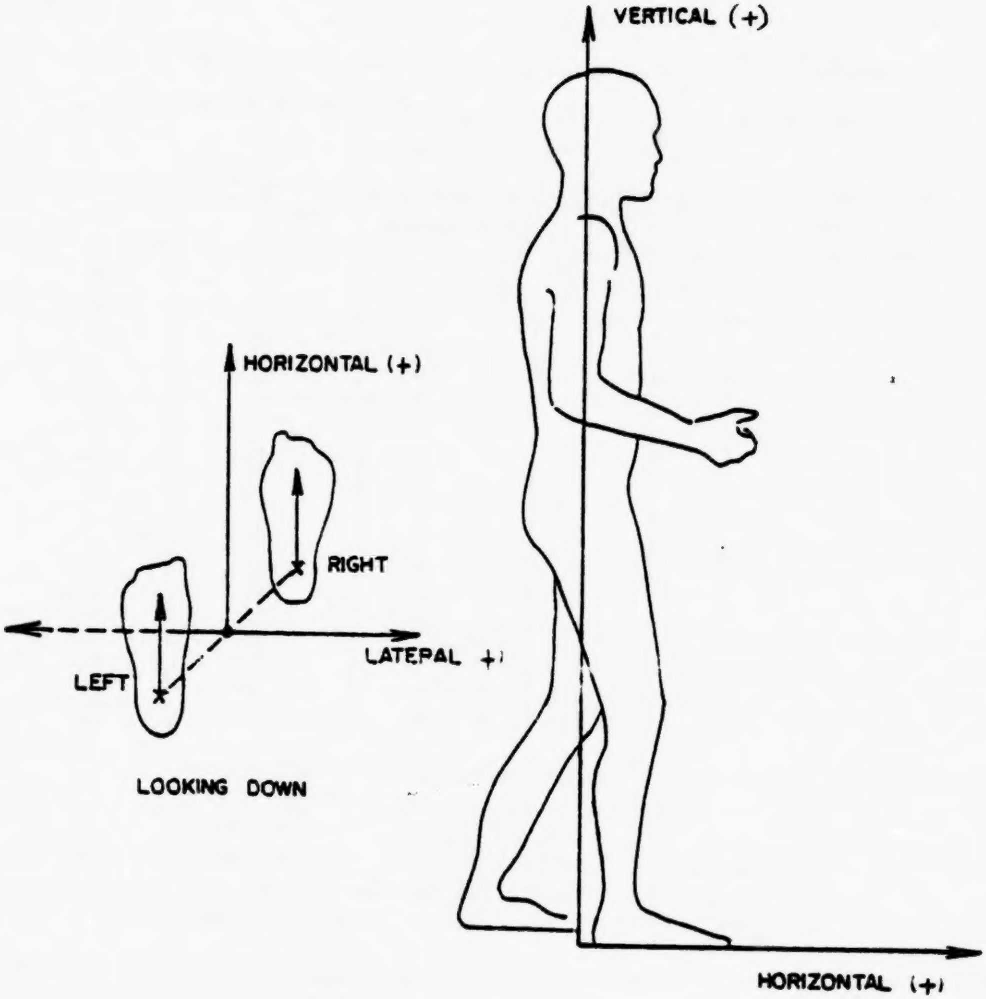

VERTICAL (+)
HORIZONTAL (+)
RIGHT
LATERAL +
LEFT
LOOKING DOWN
HORIZONTAL (+)

Figure 8.3 Graphic Representation of Vertical, Lateral and Horizontal Axes.

4. Period (or Duration) - the total time engaged in lifting should be noted. This need only be defined as less than one hour or more than one hour for the purposes of this Guide.

Figures 8.4 through 8.7 illustrate the factor weights for each of the above task variables. These nomograms allow the analyst to quickly determine the correct factor adjustments to be applied for each variable in order to complete the latter columns of the job

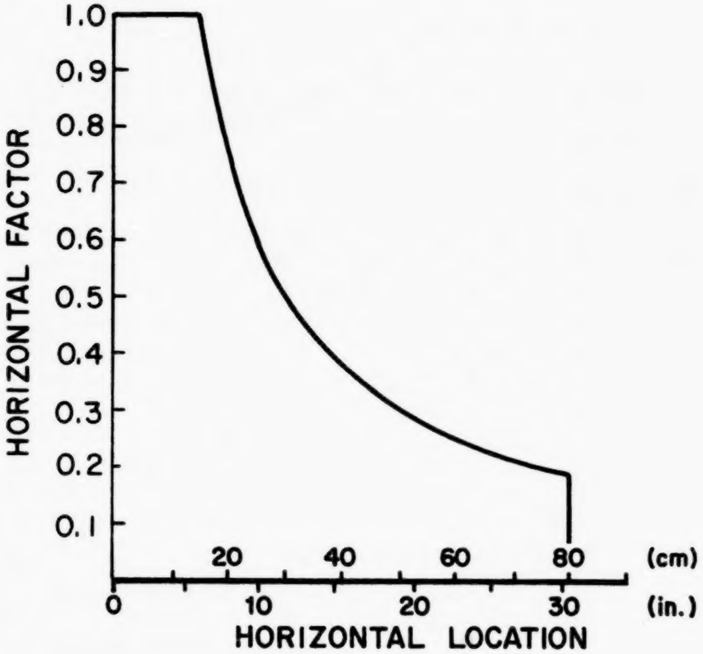


Figure 8.4: Horizontal Factor Nomogram.

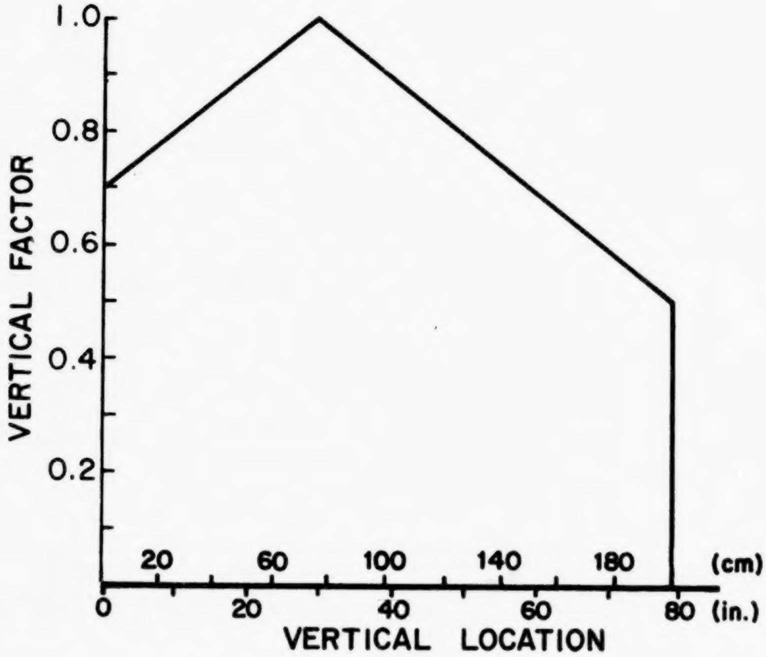


Figure 8.5: Vertical Factor Nomogram.

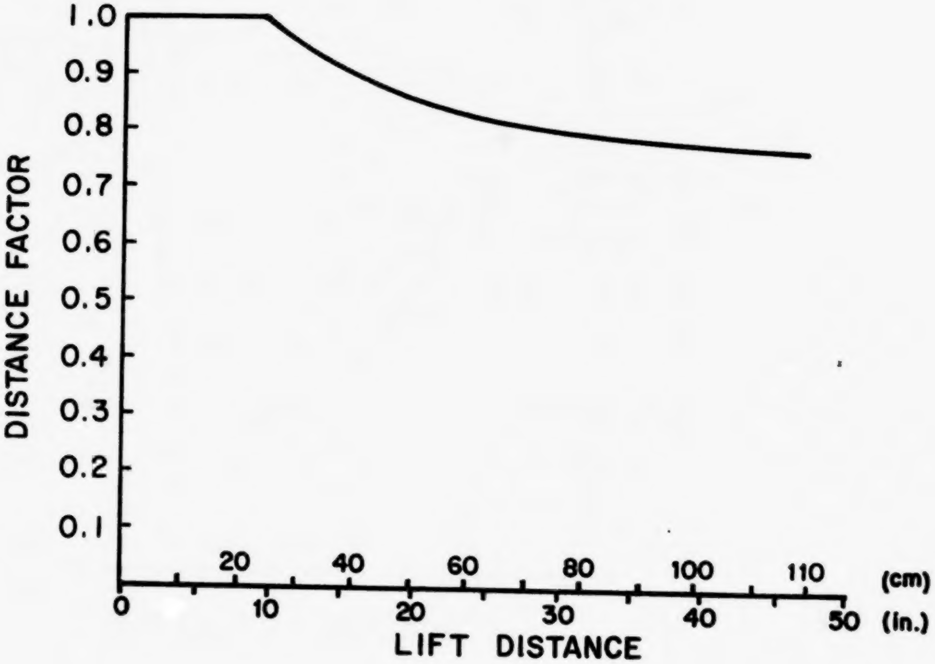


Figure 8.6: Vertical Distance Factor Nomogram.

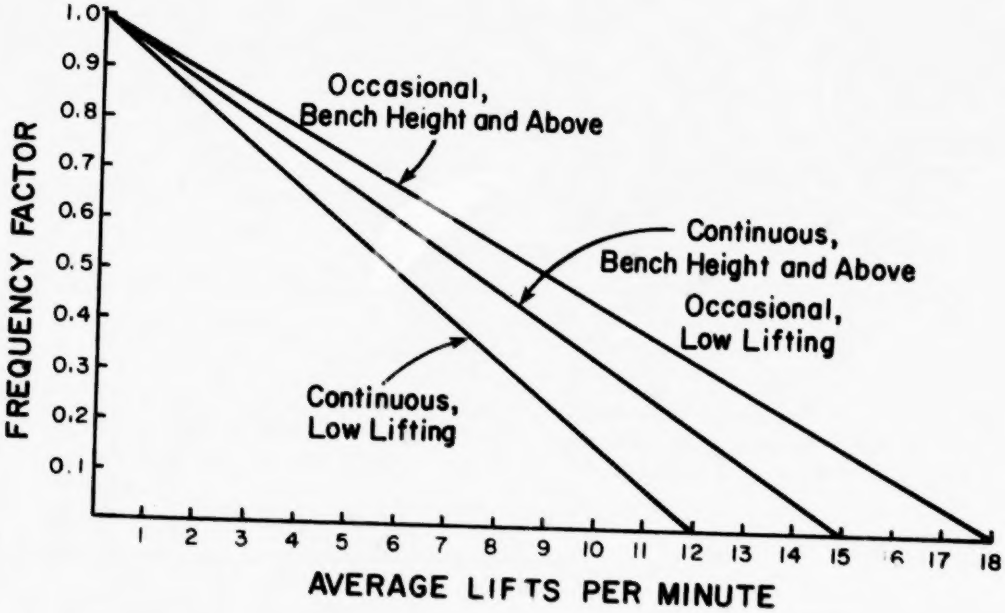


Figure 8.7: Frequency of Lift Factor Nomogram.

analysis sheet. The remarks section may be useful in describing which factor is most restrictive or limiting for each element.

EXAMPLES

Five examples will now be discussed to illustrate the analysis and interpretation of this methodology.

Example 1: Infrequent Lifting

Figure 8.8 illustrates a common misconception (or oversight) in terms of what types of jobs may be physically stressful. A punch press operator, for example, routinely handles small parts, feeding them in and out of a press. A cursory view of this task may overlook the fact that once per shift, the operator is required to load a reel of supply stock (illustrated shoulder height) from the floor onto the machine. The reel weighs 20 kg. This activity is documented in Figure 8.9. Assuming the operator lifts the reel in the plane shown (rather than on the side of the machine) the appropriate horizontal dimension is (75/2 + 15) = 53 cm or $(\frac{30}{2} + 6) = 21$ in. At the destination V = 160 cm (63 in). Since the activity occurs only once per shift, F = 0 (no frequency adjustment required).

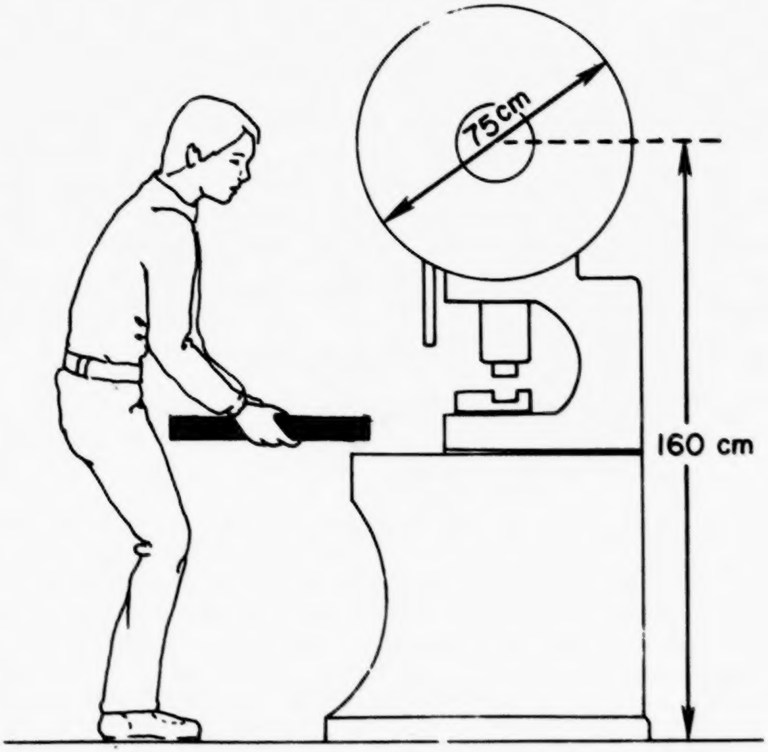
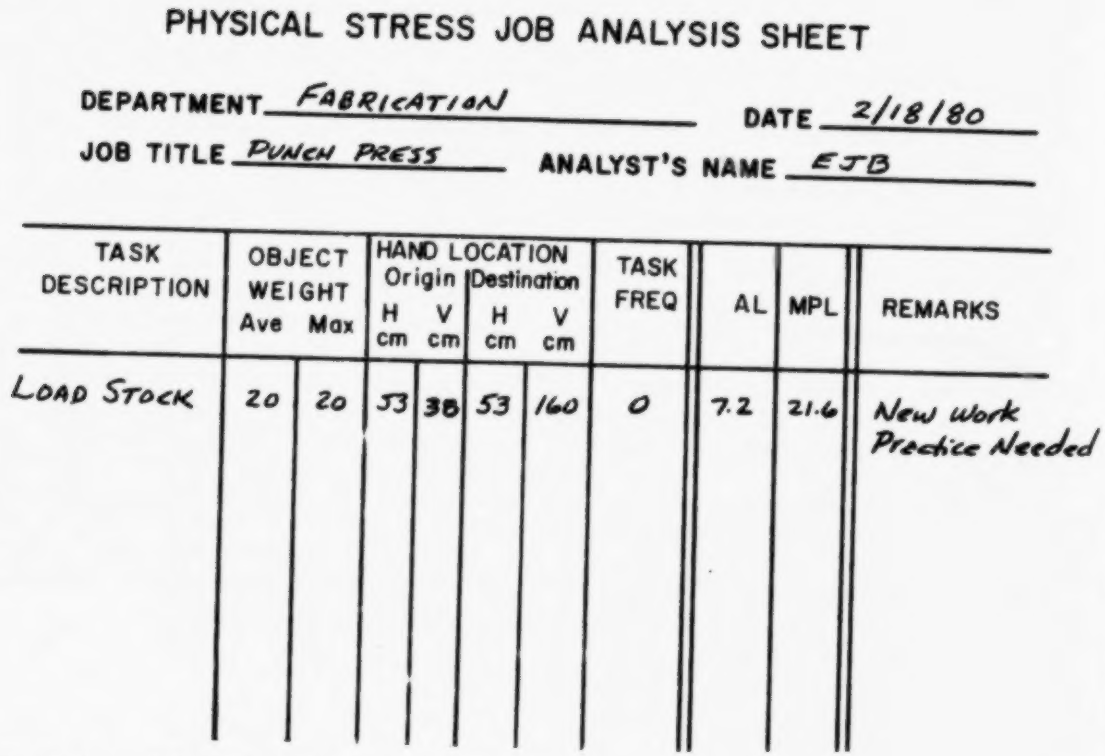


Figure 8.8: Example 1, Punch Press Operator.



PHYSICAL STRESS JOB ANALYSIS SHEET

DEPARTMENT FABRICATION DATE 2/18/80

JOB TITLE PUNCH PRESS ANALYST'S NAME EJB

TASK DESCRIPTION	OBJECT WEIGHT		HAND LOCATION				TASK FREQ	AL	MPL	REMARKS
			Origin		Destination					
	Ave	Max	H cm	V cm	H cm	V cm				
LOAD STOCK	20	20	53	38	53	160	0	7.2	21.6	New work Practice Needed

Figure 8.9: Job Analysis for Example 1.

Interpreting this activity in terms of the critical variables:

$$\text{H factor} = 15/H = 15/53 = .28$$

$$\text{D factor} = .7 + 7.5/(160-38) = .76$$

$$\text{V factor} = 1 - .004\ (75-38) = .85$$

$$\text{F factor} = 1 - 0/15 \quad = 1.0$$

Therefore

$$AL = 40(.28)(.76)(.85)(1.0) = 7.2\ \text{kg}$$

$$MPL = 3(7.2) = 21.6\ \text{kg}$$

In this case, lifting the 20 kg reel in this way would be stressful for most people and at least strong administrative controls would be required if not engineering controls.

Notice that the H factor is most critical in this case (H factor = .28). If possible, the operator should load the machine from the side (i.e., grasping the reel by its perimeter). This would allow the reel to be brought closer to the body (i.e., H = 20 cm for example). With this preferred work practice,

$$AL = 40(.75)(.76)(.85)(1.0) = 19.4$$

$$MPL = 3(19.4) = 58.2$$

For all practical purposes the activity is now within the capabilities of most people. Alternative engineering controls might include elevating the delivery of reels (above the floor) thus improving both the V and D factors.

Examples 2 and 3: H Not Constant

Evaluation of jobs where the H value is not constant throughout the lift should be approached with caution by the analyst. The most common error is to exaggerate H, making a job seem more difficult than it actually is.

For example, a compact load is lifted from the floor to a point 125 cm high as illustrated in Figure 8.10. Due to workplace constraints the object must be placed on a moving conveyor at a distance H=80 cm but the lift is unconstrained up to waist height (about 100 cm). In most cases, the load can be lifted close to the body up to this point and then through transfer of momentum be placed on the conveyor with little difficulty. Using an H value of 80 cm greatly overestimates the strength requirements of this task. As a general rule of thumb, the analyst should use the H value at the origin (in this case close to the body) to determine the weight limit and not the H value for the end point of the lift. However, a fragile load that must be carefully handled throughout the lift may well require the strength capabilities of lifting the load from the floor to the end point at an H value equal to that of the end point!

The estimation of horizontal location as W/2 + 15 cm for body clearance is not appropriate with horizontal obstructions such as illustrated in Figure 8.11. In this case, the appropriate horizontal dimension is 60 cm at the origin. Presumably the load is not fragile, nor need it be retrieved from the destination. If it must be retrieved the horizontal location at the destination will become the origin for a subsequent lift!

Example 4: Occasional High Frequency Lifting of Constant Weights

Suppose that for a period of one hour, a person unloads palletized cartons each weighing 5 kg stacked 5 high onto a conveyor as illustrated in Figure 8.12. In this case the vertical origin location

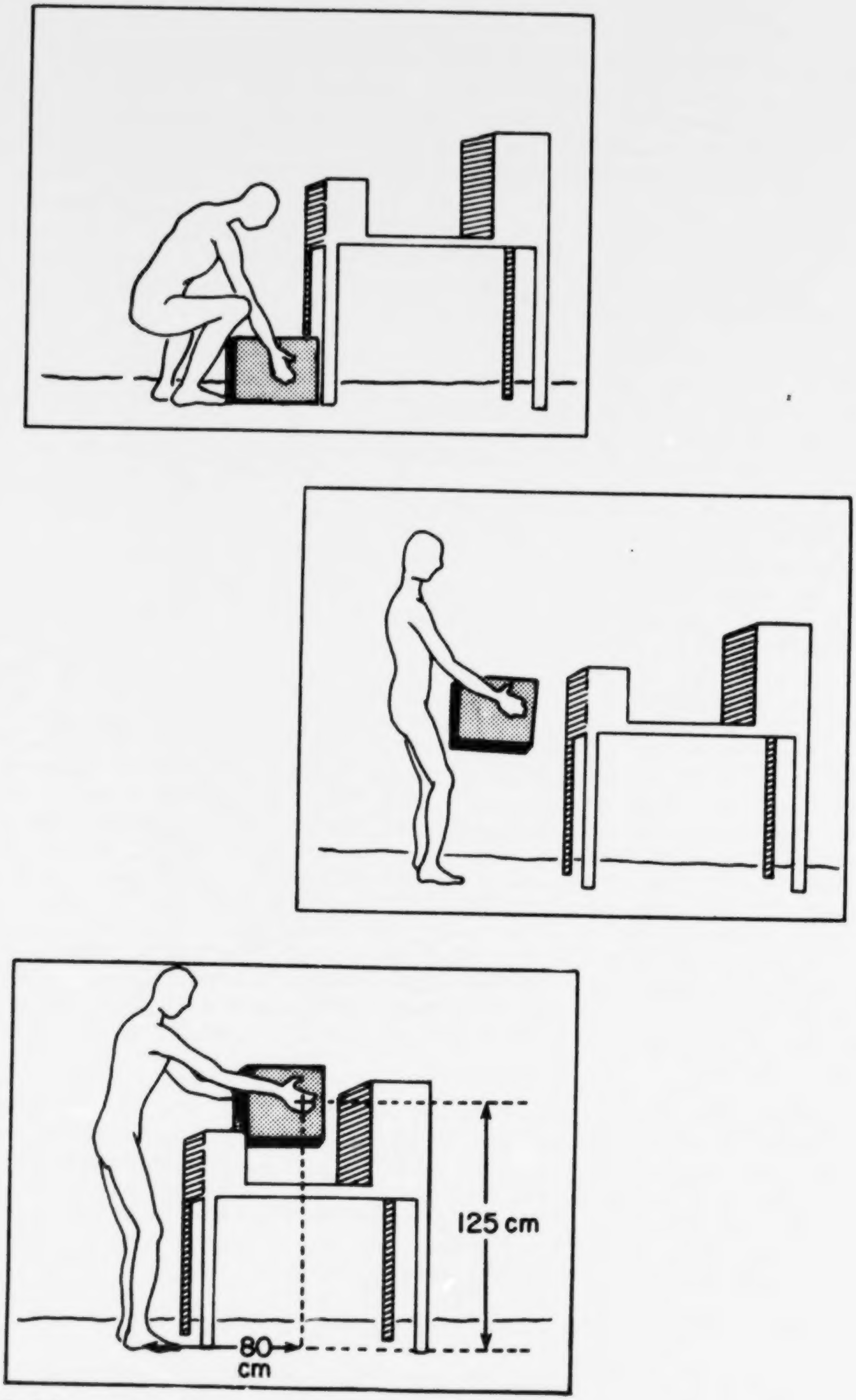


Figure 8.10: Example 2, Transfer of Momentum.

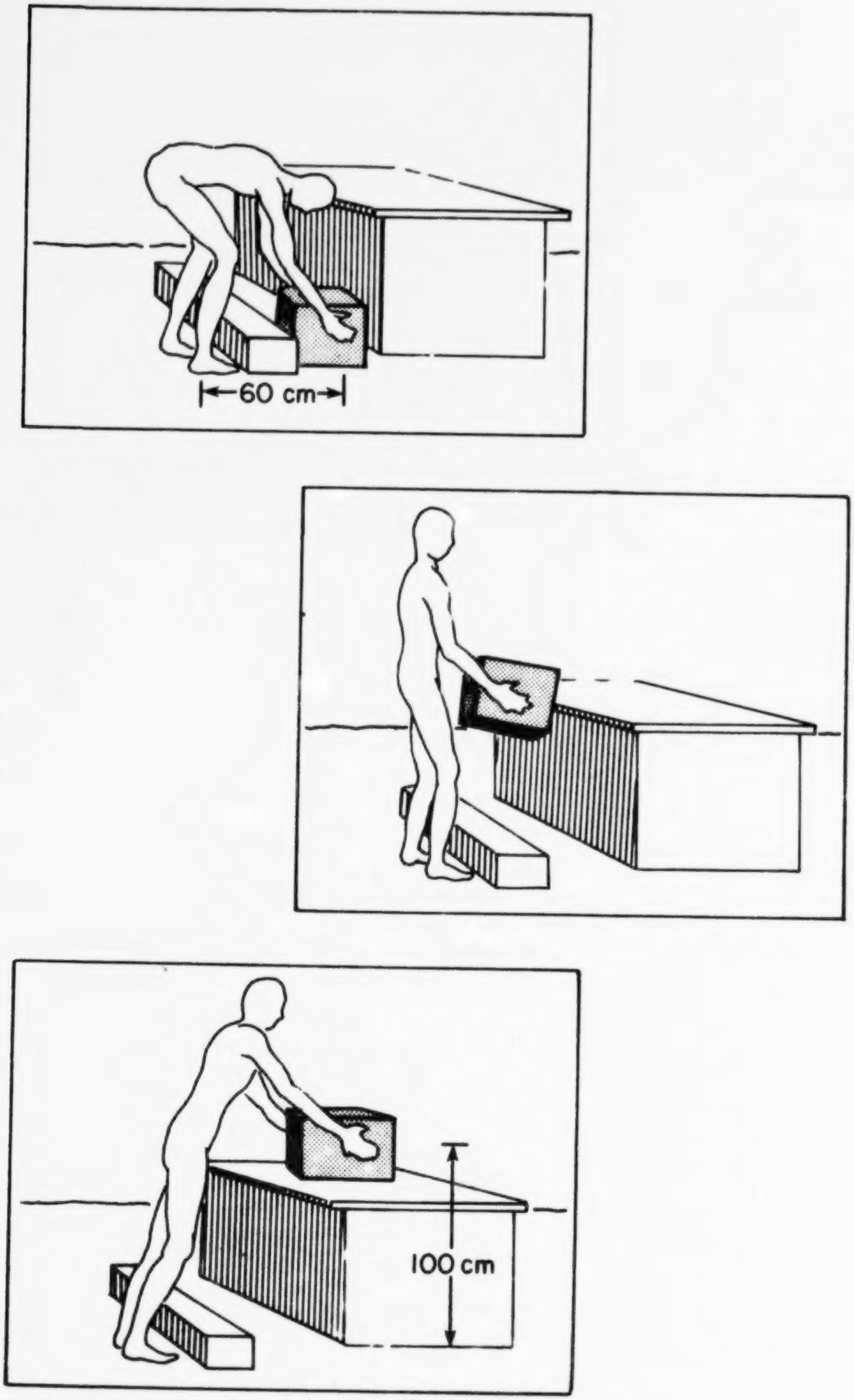


Figure 8.11: Example 3, Horizontal Obstruction.

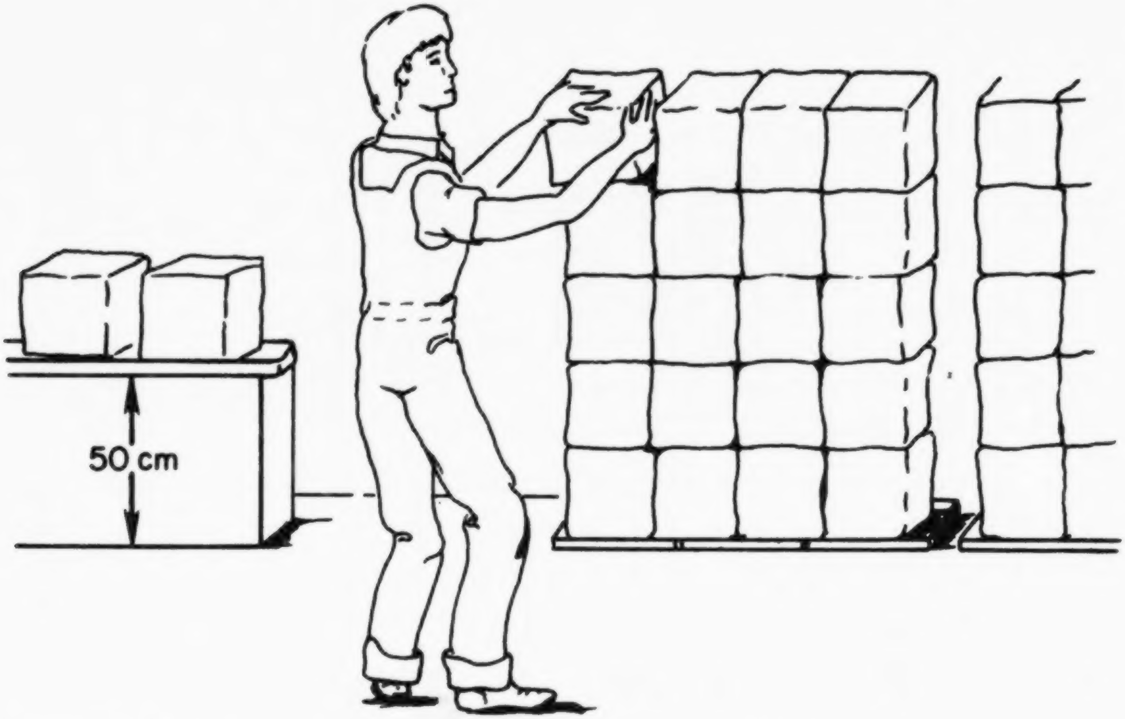
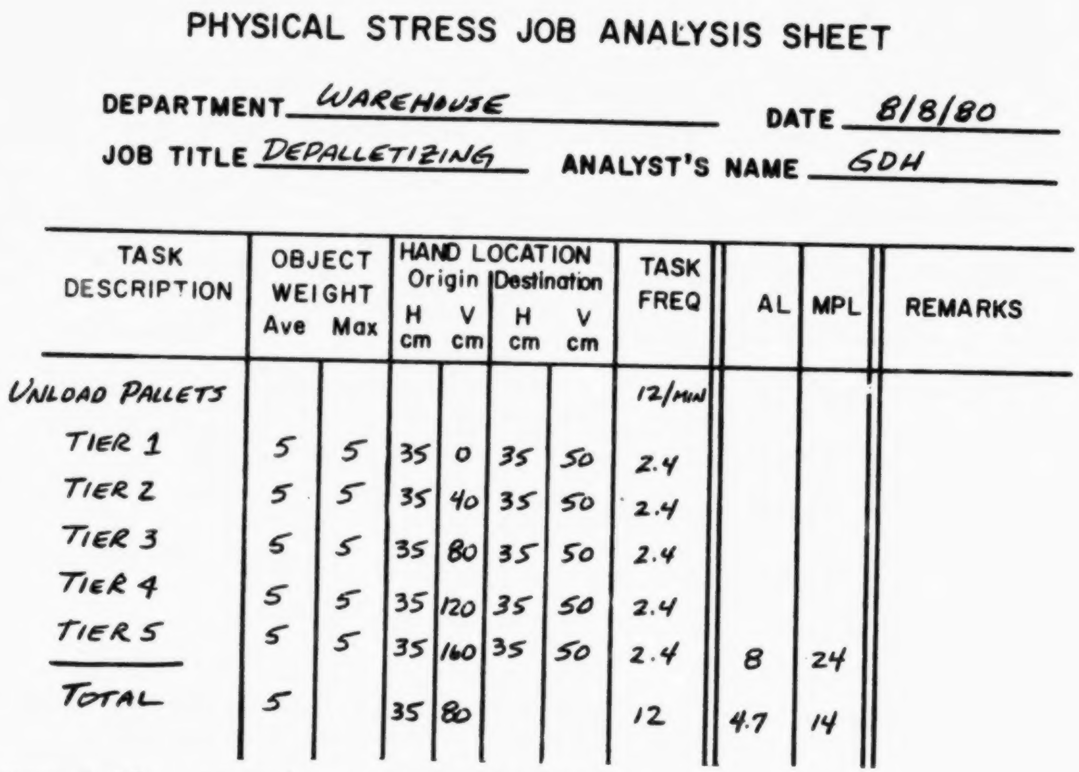


Figure 8.12: Example 4, Depalletizing Operation.

(V) and vertical travel (D) vary from one lift to the next. Also note that this task requires both lifting and lowering (for those high cartons) as well as possibly some twisting and carrying. These later aspects are outside this Guide and their effects should be minimized by a slowed pace for lifting and delivering pallets as close to the conveyor as possible.

Figure 8.13 presents an analysis which approximates the stresses of this activity assuming the carton dimensions are 40 cm x 40 cm x 40 cm, unloaded 12 per minute, and the person is free to climb over the pallet to get close to each carton. Basically the job is divided into 5 tasks representing the 5 tiers of the loaded pallet. The base frequency (12/min) is divided between each tier (2.4 lifts/min/tier). The horizontal location is estimated as H = (15 + 40/2) = 35 cm. The vertical locations at the origin represent the position of the hands under the cartons (ignoring the pallet height for purposes of this example).

Two separate analyses are warranted in this case. Each task should be analyzed separately and then collectively. The most stressful task (or tier) is task 5. For this task the V factor = (1 - .004(160-75)) = .66. The V factors for each of the other tasks will



PHYSICAL STRESS JOB ANALYSIS SHEET

DEPARTMENT WAREHOUSE DATE 8/8/80

JOB TITLE DEPALLETIZING ANALYST'S NAME GDH

TASK DESCRIPTION	OBJECT WEIGHT		HAND LOCATION				TASK FREQ	AL	MPL	REMARKS
			Origin		Destination					
	Ave	Max	H cm	V cm	H cm	V cm				
UNLOAD PALLETS							12/MIN			
TIER 1	5	5	35	0	35	50	2.4			
TIER 2	5	5	35	40	35	50	2.4			
TIER 3	5	5	35	80	35	50	2.4			
TIER 4	5	5	35	120	35	50	2.4			
TIER 5	5	5	35	160	35	50	2.4	8	24	
TOTAL	5		35	80			12	4.7	14	

Figure 8.13: Example 4, Analysis Sheet.

be larger since this vertical origin is most distant from 75 cm. Note that with more complicated tasks such a simplification will not necessarily be possible. It is only possible with this job since all other variables remain constant.

For this most stressful task, then

$$AL = 40\ (15/35)(.66)(.7+7.5/110)(1-2.4/18) = 8\ \text{kg}$$

$$MPL = 3\ (8) = 24\ \text{kg}$$

It is concluded that individually the elements of the job are quite reasonable (5 kg is below the AL).

Now consider the tasks collectively. The following approximation is not exact but should provide a reasonable composite estimate. Derive a weighted average for each variable in the job analysis according to frequency. In this case frequency is constant across tasks and vertical origin and travel distance are the only factors which vary.

The average vertical location is

$$V = \frac{0 + 40 + 80 + 120 + 160}{5} = 80 \text{ cm}$$

The average vertical travel is

$$D = \frac{50 + 10 + 30 + 70 + 110}{5} = 54 \text{ cm}$$

For the total job then

$$\begin{aligned} AL &= 40\ (15/35)(1-.004(5))(.7+7.5/54)(1-12/18) \\ &= 40\ (.43)(.98)(.84)(.33) \\ &= 4.7 \text{ kg} \\ MPL &= 14 \text{ kg} \end{aligned}$$

Since the carton weight (5 kg) is nominally above the AL, administrative controls may be required. The analysis suggests that the problem with this job is not so much strength (at issue in the individual task analysis) but endurance. Since a number of simplifying assumptions were made in this analysis a more detailed metabolic analysis of such a job may be warranted before implementing administrative controls. Such an analysis is described in detail by Garg, et al., (1978).

Example 5: Continuous High Frequency Lifting, Variable Tasks

Lifting tasks of this type are typical in warehousing, shipping and receiving activities where there are many different sized loads of varying weights that are lifted at varying frequencies. As a simple example, consider a job with the set of 3 tasks described in Figure 8.14.

For highly variable jobs (such as this one) this Guide is most limited. Following the procedure of the preceding example, each task should first be examined individually. The recommended AL and MPL for each task is as follows:

TASK 1:

$$\begin{aligned} AL &= 40\ (15/40)(1-.004(75))(.7+7.5/75)(1-1/12) \\ &= 40\ (.38)(.70)(.80)(.92) = 7.8 \\ MPL &= 23.4 \end{aligned}$$

PHYSICAL STRESS JOB ANALYSIS SHEET

DEPARTMENT Receiving DATE 5/1/80

JOB TITLE Loader ANALYST'S NAME CKA

TASK DESCRIPTION	OBJECT WEIGHT		HAND LOCATION				TASK FREQ	AL	MPL	REMARKS
			Origin		Destination					
	Ave	Max	H cm	V cm	H cm	V cm				
Product A	10	40	40	0	50	75	1	7.8	23.4	Reduce product variability
Product B	15	30	30	0	30	15	2	11.6	34.8	
Product C	5	10	15	75	20	100	5	26.8	80.4	
Total	8.1		22	47			8	7.7	23.1	

Figure 8.14: Example 5, Highly Variable Job.

TASK 2: AL = 40 (15/30)(1-.004(75))(.7+7.5/25)(1-2/12)

= 40 (.50)(.70)(1.0)(.83) = 11.6 kg

MPL = 34.8

TASK 3: AL = 40 (15/15)(1-.004(0))(.7+7.5/25)(1-5/15)

= 40 (1.0)(1.0)(1.0)(.67) = 26.8 kg

MPL = 80.4 kg

Two technical aspects of the above calculations are noteworthy:

a. Travel distances less than 25 cm should be considered as 25 cm. In task 2, this cutoff was used. (Factors must all be less than or equal to 1.0).

b. Since this job is performed continuously, F_{max} factors (from Table 8.2) of 12 and 15 were used for lifts from less than and greater than 75 cm.

Based on this elemental analysis it can be concluded that Tasks 1 and 2 are the most stressful. In fact, the maximum weights of 40 kg (Task 1) are above the MPL = 23.4 and engineering controls (such as mechanical aids or two-person lifting) are warranted. Note that the average weights in Task 1 (10 kg) are reasonable with administrative controls. In both cases, the horizontal location produces the greatest discount in ability. Task 3 appears to be nominal in terms of physical stress.

As with Example 4, analysis of the combined elements of the job can only be approximated by computing weighted averages according to frequency. In this case, the composite

$$H = \frac{1(40) + 2(30) + 5(15)}{8} = 22 \text{ cm}$$

The coefficients 1, 2, and 5 correspond to each elemental frequency and 8 is the total number of lifts per minute.

Similarly, the weighted average

$$V = \frac{1(0) + 2(0) + 5(75)}{8} = 47$$

$$D = \frac{1(75) + 2(15) + 5(25)}{8} = 29$$

$$F = 1 + 2 + 5 = 8$$

Thus, for the combined tasks:

$$AL = 40\ (15/22)(1-.004(75-47))(.7+7.5/29)(1-8/12)$$

$$= 40\ (.68)(.89)(.96)(.33) = 7.7 \text{ kg}$$

$$MPL = 23.1 \text{ kg}$$

Since the average weight lifted is 8.1 kg, administrative controls are required.

It is important to note that this "averaging" of the task descriptors in this case tends to dampen out the large differences between the tasks. This is true in general (but not always). This error and the errors introduced by ignoring other carrying, holding, pushing, and pulling tasks can only be resolved with more detailed biomechanical, metabolic, and psychophysical evaluations.

ADMINISTRATIVE CONTROLS

Given the preceding detailed analysis of the physical stresses, a lifting job (or tasks within a job) can be classified into one of 3 zones:

1. Acceptable (below the AL),
2. Unacceptable for most individuals (above the MPL), or
3. Unacceptable for some individuals (between the AL and MPL).

This section deals with selecting and training of workers for jobs of the latter type (3). A more detailed discussion is presented in Chapter 6. Alternative engineering controls are then summarized for conditions 2 and 3. A more detailed discussion appears in Chapter 7.

Selection

In order to safely match a worker to the physical demands of a given task, several selection procedures can and have been used. For the many manufacturing, distribution, and service industries which have no medical staff, self-selection has been the principal method. Other methods commonly used are:

1. Questionnaires on health and medical history
2. Tests of visual, auditory and pulmonary function, blood pressure, mobility and a chest X-ray
3. Clinical examination.

The problem with these is that they are unreliable predictors of medical risk of injury. Also, the worker is usually not followed medically during the first few weeks of training when many postural stress related problems could be prevented.

In view of these problems, routine lumbar spinal radiography has often been prescribed by occupational medical advisors as a prerequisite for employment in heavy manual work. Using X-rays for this purpose, however, is very controversial because:

1. There have not been any statistically significant differences shown in the incidence of radiological abnormalities between workers with known history of back pain and those without.
2. There is a problem of X-ray interpretation. No reliable data exists on the predictive rating for observed abnormalities. It is also impossible to quote a value for the increased probability of back trouble for different abnormalities.

3. X-rays present a radiation hazard, particularly for females who cannot be given adequate gonadal protection.

In summary, caution must be exercised in using the lumbar spinal radiograph as a selection tool. If so, it should be performed by an experienced physician after a thorough interview and examination, and with full knowledge of the MMH job concerned.

Physical Assessment of Workers

What is needed is an objective means for assessing the physical capabilities of a worker who is being considered for a certain job. In providing such an assessment certain medical, social and economic criteria must be met, these are:

1. Is it safe to administer?
2. Does it give reliable, quantitative values?
3. Is it related to specific job requirements?
4. Is it practical?
5. Does it predict the risk of future injury or illness?

As we have seen, the low back X-ray fails to some degree in each of these criteria, particularly in those relating to safety and reliability. As an alternative, worker strength testing and aerobic capacity testing have been proposed as means to meet these objectives. If carefully administered they appear to satisfactorily meet each of the above criteria as discussed in Chapter 6.

Training

The importance of training in manual materials handling in reducing hazard is generally accepted. What is lacking, however, is a clear definition of what the training should be and how it should be taught. Most controlled studies of training have shown it to be ineffective in reducing accidents and injuries related to lifting. Despite this, however, some form of training in manual materials handling jobs is likely to continue. What follows is a suggestion of what a training program should include.

1. What should be taught.

   The aims of training for safety in lifting should be:

   a. To make the trainee aware of the dangers of careless and unskilled lifting.

   b. To show them how to avoid unnecessary stress.

c. To teach the worker individually to become aware of what he/she can handle comfortably without undue effort.

In order for the training to be effective, the instructors must be well versed in the sciences basic to manual materials handling and in Safety Engineering. The content of the course must also be suited to the educational background of the trainees.

The course should cover the following aspects:

a. The risks to health of unskilled lifting: Case histories from the organization concerned provide the best illustration.

b. The basic biomechanics of lifting: The body as represented by a system of levers.

c. The effects of lifting on the body: The basic anatomy of the spine and the muscles and joints of the trunk; the contribution of intra-thoracic pressure while lifting.

d. Individual awareness of the body's strengths and weaknesses: How to estimate one's comfortable lifting capacity.

e. How to avoid the unexpected: Recognition of the physical factors which might contribute to an accident.

f. Handling skill: Safe lifting postures; minimizing the load - moment effects; timing for smooth and easy lifting.

g. Handling aids: Platforms, stages or steps, trestles, handles, wheels, shoulder pads.

h. Warnings: What to be aware of when lifting.

2. How it Should be Taught.

It is not enough to teach safe lifting practices by slides or films. The trainee should be practically involved from the start. Therefore, classes must be small. Training should not be restricted to a classroom. Lifting technique should be demonstrated and practiced at the work site. Supervisors, as well as trainees, should be involved in the training program. The following are the steps to an effective training program:

a. Begin with a poster campaign drawing attention to the need to do something about lifting accidents and back injuries, changing them every few days.

b. Organize a training session for managers and supervisors.

c. Present the training course to small groups of employees.

d. Have the plant doctor and the team of instructors tour the plant, discussing any points put to them by the workers.

e. Continue to make plant tours at regular intervals.

In summary, there is a vital need for training to be both in the classroom and on the site, to involve all levels of workers including executives, and to be monitored routinely throughout the factory in order for the program to be effective.

ERGONOMIC/ENGINEERING CONTROLS

More important than proper selection and training in the long term prevention of accidents and injuries related to lifting, is providing a safe ergonomic environment in which to work. This includes factors of the mechanical environment (such as container design, human/container coupling design, worker/floor surface coupling), the visual environment and the thermal environment.

Mechanical Environment

1. Container Design. From the biomechanical considerations discussed in Chapter 3, containers should be as small as possible. A compact load minimizes the compressive forces applied to the L_5/S_1 disc because the load center of gravity can be brought close to the spinal column - oftentimes between the legs, which reduces disc pressure even more. Another important factor in container design is the load center of gravity. Baffles, dividers or packing should be used to keep the center of gravity in a constant position because any shifting of the load could contribute to human error in manual handling.

   Anthropometry plays an important part in recommending the maximum dimension of a container. If the forward edge is to be reached, the length should not exceed 70 cm (males) or 65 cm (females). To prevent interference with forward vision, the maximum height of the container above handle position should be 83 cm (males) and 80 cm (females). Also handles should be placed so that the whole container is above hip height when the elbows are extended.

2. Human/Container Coupling Design. Handles on containers should be designed with the worker's hand in mind. They have a large effect on both the maximum force a worker can exert on a container and on the energy expenditure in manual materials handling tasks. The major problems with most handles are insufficient hand clearance, sharp edges which can cut into the hand and too small of a handle diameter.

   The postures of the hand with respect to grasped objects can be classified as follows:

   a. Hook grip. One in which the fingers are flexed around the object and the thumb is not used for gripping.

   b. Power grip. One in which the object is clamped between the partly flexed fingers and palm with the thumb opposing the grip and lying along the plane of the palm.

   c. Precision grip. One in which the object is pinched between the flexor aspects of the fingers and opposing thumb.

   Most handles force the worker to use the hook grip (the least effective) or the power grip. The power grip gives a good gripping force and allows a large surface of the hand to be used but often is inefficient if accurate control is needed. The weight of the object often prevents the precision grip from being used.

   There is little agreement in the literature as to what the optimum handle diameter is, but from 25 mm (1 inch) to 38 mm (1.5 in.) is the range into which most recommendations fall. The elimination of sharp edges, seams, rubbing, and corners appears to be of more importance than actual handle diameter. The shape of the handle is better cylindrical than molded to the contours of the hand.

   Handle width should be at least 11.5 cm (4.5 in.) with 50 mm (2 inches) clearance all around the handle to accommodate a 95th percentile hand. If gloves are used, at least 25 mm (1 inch) should be added to these dimensions.

3. Worker/Floor Surface Coupling. Poor worker/floor coupling will most often result in accidents such as slips, trips, or missteps. The major mediating variable in these types of accidents is the coefficient of friction between the shoe sole and the working surface. This can be affected by:

a. work surface materials

b. surface coating

c. floor condition

d. floor angle

e. shoe sole/heel composition and contact area

f. shoe style

The general recommendation is to adjust shoes and working surfaces to give a coefficient of static friction of at least .4 and preferrably .5.

Unnoticed changes in surface friction can also cause accidents. These can be reduced by:

a. ensuring that different surface materials or coatings have transition zones between them,

b. clearly marking any surface friction change,

c. using good housekeeping procedures to reduce transient changes in surface friction such as spills, worn spots, loose or irregular floors.

Because of the forces transmitted from the container to the body when lifting, good work/floor coupling is essential in controlling accidents and injuries resulting from foot slippage.

The Visual Environment

While manual materials handling operations rarely demand the fine visual discrimination of delicate assembly work, they do require control of the visual environment for optimum performance and safety. The task of lifting involves vision of the container, the workplace around the container and the surface on which the operator stands. An illuminance of 150 lux (14 foot-candles) in each of these areas is a recommended minimum.

Types of lifting can have a large effect on visual performance, particularly in the areas of depth perception and surface texture perception. Differences in contrast or differential illumination can be used to make stairs or changes in walking surfaces easily discernible. Low, angled illumination is recommended for enhancing surface texture to warn operators of changes in shoe/surface friction. Depth perception errors can be controlled by changing reflectance of the container and task to provide additional contrast. Color contrast can be used on edges of steps, loading docks and ramps when the consequences of misperception are severe.

Labeling can be used to indicate handhold positions, cautions against single person lifting if the load is heavy, or a note of caution if its center of gravity is not near the center or if it is likely to shift.

The Thermal Environment

Deviations from the comfort zone (18°C (64.5°F) to 21°C (70°F) have been shown to influence injuries in many industries. It is thus particularly important to ensure that thermal stress does not contribute to manual materials handling safety problems.

Cold environments are not usually a problem in manual materials handling because the strenuous nature of the work provides sufficient heat production, and the thermal clothing may provide some personal injury protection. The cold, however, does reduce dexterity which could lead to human error in lifting.

If a heat stress problem is suspected, it should be assessed by the Wet Bulb Globe Temperature (WBGT) index. Recommendations for this index can be found in the ACGIH (1980). Engineering control measures such as radiant heat shielding, forced air movement, clothing design and work-rest schedules can be used to prevent body temperatures from increasing over the 38°C (100.4°F) recommendation.

Materials Handling System Alternatives

Jobs which exceed the MPL should be performed with the aid of some mechanical device or redesigned so that they can be performed safely. Some examples of simple lifting aids found at the workplace are:

a. Hooks: The worker should be trained in the use of handling packing hooks so that they will not glance off hard objects.

b. Bars: The major hazard of a crow bar is that it may slip. The edge should have good "bite".

c. Rollers: These are effective in moving heavy and bulky objects.

d. Jacks: They should be marked to indicate the safe load which can be raised.

e. Platforms: These provide the maintenance of a convenient height for lifting and handling.

f. Trestles: These can be used to maneuver long loads on the point of balance, or for readjusting the grip or carrying posture.

Other types of mechanical aids are:

a. Conveyors are used primarily when loads are uniform, movement is from one point to another, and materials move constantly.

b. Cranes and Hoists are most commonly used when loads vary in size and weight, moves are intermittent, and cross traffic will interfere with conveyors.

c. Industrial trucks are most often used when materials are moved intermittently, over varying routes, when cross traffic would prohibit conveyors, and loads are uniform or mixed in size and weight.

Potential Safety and Ergonomic Problems

Reducing the physical hazards or manual lifting to the musculoskeletal system can often result in other types of safety problems. Some of these are:

a. Conveyors: Aside from mechanical entrapments, the major problem with conveyors is that the work is externally paded. This can cause time-stress induced errors. Conveyor designs which take into account the cycle-to-cycle variability of the operator can reduce such stress. Buffer stocks between stations achieve the same effect.

b. Cranes and Hoists: Because of the dangers involved when a load is suspended, cranes are among the most hazardous of material handling equipment. The crane cab and all controls should be designed for good visibility and safe operation. The loading capacity of the crane should be clearly marked. Standard signals should be used between the crane operator and the signalman on the ground.

c. Hand Trucks: Safety hazards include falling of the load, collision between the truck and other objects, and the operator getting pinned between the truck and another object. These can be reduced by such design features as: covering all exposed handles with knuckle guards, guarding or recessing all wheels, brakes that apply automatically when the handle is either fully raised or fully lowered, or released.

CONCLUSION

It has been traditional to bemoan the existence of widely divergent recommendations for maximum weights which can be safely lifted. These divergent recommendations have actually been due to the differences in what is accepted as a reasonable criterion by different scientific disciplines. This Guide has attempted to integrate the conclusions of four distinctive disciplines within the broad field of Ergonomics into one set of recommendations. Obviously, the recommendations do not satisfy any of the criteria perfectly and considerable qualification of the specific aspects of lifting were required in order to arrive at any consensus.

The convergence between the methodologies, however, overshadows the differences. The fact that these technologies agree on the major factors which limit lifting ability and even point to similar absolute magnitudes is strong evidence that the guidance is sound. This guidance will only be effective, though, if it is carefully studied and applied within your workplace.

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APPENDIX

This appendix contains a sensitivity analysis of the work practice guide equation presented in Chapter 8. For a variety of vertical and horizontal hand locations, vertical travel distances, and frequencies of lifting, the action limit (AL) and maximum permissible limit (MPL) are evaluated in terms of:

1. the expected percent of the workforce capable based on dynamic strength, Ayoub, et al., (1978) and Snook (1978),
2. the range of expected percent of the workforce capable based on isometric strength, Chaffin, et al., (1978),
3. the lower and upper bounds on predicted static compressive force at the L_5/S_1 vertebral level, Chaffin, et al., (1978), and
4. the range of predicted metabolic rates according to Garg, et al., (1978).

In all cases, the AL is evaluated based upon a female industrial population; the MPL is based upon a male industrial population.

Ranges for the last three indices were obtained by calculating these values for both the least- and most-desirable posture. For example, the metabolic expenditure for low lifting in a squat posture is greater than when lifting in a stoop posture (see Chapter 4). Therefore, the value corresponding to the squat posture is least preferred and represents the upper bound on metabolic rate. The lower value corresponds to a stoop posture. No range is given when the vertical hand location is 81 cm or higher because it is assumed that only a stand posture would be appropriate for lifting. A detailed explanation of the derivation of values for each column follows.

DYNAMIC % CAPABLE

The table value is calculated by obtaining the standard normal distribution Z-value for the given vertical and horizontal hand location, travel distance and frequency suggested in Chapter 5 (Table 5.7). For the Action Limit (Table A.1) the ranges assumed were as follows:

floor to knuckle: 15 cm and 50 cm vertical
knuckle to shoulder: 75 cm and 125 cm vertical
shoulder to reach: 150 cm and 175 cm

A horizontal hand location (in the sagittal plane) of 46 cm is assumed. The complementary cumulative probability of the standard normal distribution is recorded in the table as the expected percent capable for the given set of conditions. The values in Table 5.7 for males were, likewise, used to obtain the percent capable for the MPL in Table A.2.

ISOMETRIC % CAPABLE

The table value is obtained by entering the vertical and horizontal hand locations and the AL into the biomechanical model reported by Chaffin, et al., (1978). The following postures were also assumed:

deep squat, squat or stoop: 15 cm and 50 cm vertical
squat or stoop: 75 cm vertical
stand: 125 cm, 150 cm and 175 cm vertical

The minimum and maximum female percent capable for the various postures are entered in Table A.1. Lateral hand separation was assumed to be 20 cm. It should also be noted that this biomechanical model assumes average male and female anthropometric dimensions. The same procedure was used for the MPL (Table A.2) but values represent the percent of the male workforce capable.

BACK COMPRESSION

Tables A.1 and A.2 present upper and lower bounds on static back compressive force obtained with the same input to the biomechanical model used for (isometric % capable) above. The larger value is the maximum back compression obtained for the various postures and the lower value is the minimum back compression for the given set of conditions.

Once again, the upper and lower bounds on back compression for the AL represent biomechanical model output for the female working population (Table A.1) and bounds for the MPL (Table A.2) represent male back compression estimates. Preferred and least desirable postures are not necessarily the same for males versus females or strength versus back compression.

METABOLIC RATE

The Garg, et al., (1978) equation presented in Chapter 4 was used in the estimation of the expected metabolic rate (Kcal/min.). Female 50 percentile body weight was used when calculating the rate corresponding to the AL, and 50 percentile male body weight for the rate corresponding to the MPL. Also, basal metabolic rate for a bent standing posture was assumed when the vertical hand position was 81 cm or less (irrespective of the travel distance), whereas the basal rate for a standing posture was used otherwise (i.e., 82 cm and above). The lower value corresponds to an assumed stoop lift and the larger value assumes a squat lift. Obviously, such a range can only be calculated when the lift begins below 81 cm. Above 81 cm, the equation for an arm lift was used to calculate the metabolic expenditure per lift.

For frequencies of .2 lifts per minute, the metabolic rates represent basal metabolic rates. Horizontal hand location is not accounted for in these estimates.

Table A.1: Action Limit Sensitivity Analysis

V (cm) VERT	H (cm) HORZ	D (cm) DIST	F (per min)	ACTION LIMIT (AL)	DYNAM % CAP	ISOMETRIC % CAPABLE		BACK COMPRESS.		MET. RATE	
						LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
15	15	25	<.2	30	---	82	92	154	316	1.8	1.8
			1	28	---	85	94	149	297	2.0	2.2
			10	5	---	---	---	111	146	3.3	4.2
15	15	75	<.2	24	---	88	96	143	273	1.8	1.8
			1	22	---	90	97	140	260	2.2	2.4
			10	4	---	---	---	110	142	3.7	4.7
15	45	25	.2	10	---	87	90	246	271	1.8	1.8
			1	9	98	89	92	239	262	2.0	2.1
			10	2	99	---	---	162	191	3.2	4.0
15	45	75	<.2	8	---	91	93	231	254	1.8	1.8
			1	7	99	92	94	224	245	2.0	2.2
			10	1	99	---	---	156	186	3.3	4.2
15	75	25	<.2	6	---	39	75	284	367	1.8	1.8
			1	6	---	42	77	278	360	2.0	2.1
			10	1	---	---	---	215	278	3.2	4.0
15	75	75	<.2	5	---	45	80	272	352	1.8	1.8
			1	4	---	48	88	265	342	2.0	2.1
			10	1	---	---	---	215	278	3.3	4.1
50	15	25	<.2	36	---	56	97	317	375	1.8	1.8
			1	33	---	66	97	305	362	2.0	2.1
			10	6	---	---	---	163	232	2.7	3.2
50	15	74	<.2	29	---	81	98	286	340	1.8	1.8
			1	26	---	87	99	276	330	2.3	2.4
			10	5	---	---	---	157	228	3.4	3.9
50	45	25	.2	12	---	88	96	295	362	1.8	1.8
			1	11	93	90	97	283	348	1.9	2.0
			10	2	99	---	---	166	243	2.5	2.9
50	45	75	.2	10	---	94	97	265	326	1.8	1.8
			1	9	99	95	98	254	316	2.0	2.1
			10	2	99	---	---	166	243	2.9	3.3
50	75	25	.2	7	---	71	80	349	374	1.8	1.8
			1	7	---	74	82	342	365	1.9	2.0
			10	1	---	---	---	262	268	2.5	2.9
50	75	75	.2	6	---	80	87	329	349	1.8	1.8
			1	5	---	83	89	322	341	2.0	2.0
			10	1	---	---	---	255	260	2.8	3.1

Table A.1 (cont.)

V (cm) VERT	H (cm) HORZ	D (cm) DIST	F (per min)	ACTION LIMIT (AL)	DYNAM % CAP	ISOMETRIC % CAPABLE		BACK COMPRESS.		MET. RATE	
						LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
75	15	25	<.2	40	---	48	54	306	404	1.8	1.8
			1	37	---	59	61	291	388	2.1	2.1
			10	7	---	--	--	151	240	2.4	2.5
75	15	75	<.2	32	---	76	77	268	363	1.8	1.8
			1	29	---	82	84	257	351	2.4	2.5
			10	5	---	--	--	145	234	3.2	3.3
75	45	25	<.2	13	---	86	97	289	364	1.8	1.8
			1	12	86	89	97	280	355	1.9	1.9
			10	2	99	--	--	167	245	2.1	2.2
75	45	75	.2	11	---	94	99	258	347	1.8	1.8
			1	10	97	95	99	252	342	2.0	2.1
			10	2	99	--	--	162	240	2.5	2.6
75	75	25	<.2	8	---	77	80	353	389	1.8	1.8
			1	7	---	82	83	339	373	1.9	1.9
			10	1	---	--	--	250	272	2.1	2.2
75	75	75	<.2	6	---	86	86	325	357	1.8	1.8
			1	6	---	88	89	319	349	2.0	2.0
			10	1	---	--	--	244	265	2.4	2.5
125	15	25	<.2	32	---	--	97	243	---	1.5	1.5
			1	30	---	--	97	233	---	1.8	1.8
			10	11	---	-	--	105	---	2.5	2.5
125	15	75	<.2	26	---	-	99	204	---	1.5	1.5
			1	24	---	--	99	195	---	2.1	2.1
			10	9	---	-	--	92	---	3.7	3.7
125	45	25	<.2	11	---	--	94	182	---	1.5	1.5
			1	10	90	--	94	177	---	1.6	1.6
			10	4	99	--	--	100	---	2.0	2.0
125	45	75	<.2	9	---	--	96	160	---	1.5	1.5
			1	8	98	--	97	155	---	1.7	[illegible]
			10	3	99	--	--	89	---	2.5	2.5
125	75	25	.2	6	---	--	91	326	---	1.5	1.5
			1	6	---	--	93	318	---	1.6	1.6
			10	2	---	--	--	257	---	1.9	1.9
125	75	75	.2	5	---	--	95	303	---	1.5	1.5
			1	5	---	--	95	303	---	1.7	1.7
			10	2	---	--	--	249	---	2.3	2.3

Table A.1 (cont.)

V (cm) VERT	H (cm) HORZ	D (cm) DIST	F (per min)	ACTION LIMIT (AL)	DYNAM % CAP	ISOMETRIC % CAPABLE		BACK COMPRESS.		MET. RATE	
						LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
150	15	25	<.2	28	---	--	73	230	---	1.5	1.5
			1	26	---	--	80	215	---	1.8	1.8
			10	9	---	--	--	109	---	2.5	2.5
150	15	50	<.2	24	---	--	85	200	---	1.5	1.5
			1	22	---	--	89	191	---	1.9	1.9
			10	8	---	--	--	96	---	3.0	3.0
150	45	25	<.2	9	---	--	95	247	---	1.5	1.5
			1	9	97	--	97	236	---	1.6	1.6
			10	3	99	--	--	174	---	2.1	2.1
150	45	50	<.2	8	---	--	98	225	---	1.5	1.5
			1	7	99	--	99	220	---	1.7	1.7
			10	3	99	--	--	168	---	2.3	2.3
150	75	25	<.2	6	---	--	P	P*	---	1.5	1.5
			1	5	---	--	P	P	---	1.6	1.6
			10	2	---	--	--	P	---	2.0	2.0
150	75	50	<.2	5	---	--	P	P	--	1.5	1.5
			1	4	---	--	P	P	---	1.6	1.6
			10	2	---	--	--	P	---	2.1	2.1
175	15	25	<.2	24	---	--	97	196	---	1.5	1.5
			1	22	---	--	98	184	---	1.7	1.7
			10	8	---	--	--	95	---	2.5	2.5
175	45	25	<.2	8	---	--	P	P		1.5	1.5
			1	7	99	--	P	P		1.6	1.6
			10	3	99	--		P		2.1	2.1

*The currently available models suggest that reach posture (P) rather than strength is most limiting in these cases.

Table A.2: Maximum Permissible Limit Sensitivity Analysis

V (cm) VERT	H (cm) HORZ	D (cm) DIST	F (per min)	MAX PERMIS (MPL)	DYNAM % CA	ISOMETRIC % CAPABLE		BACK COMPRESS.		MET. RATE	
						LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
15	15	25	<.2	91	---	53	64	255	786	2.2	2.2
			1	84	---	67	76	244	730	2.8	3.0
			10	15	---	--	--	140	256	4.6	5.8
15	15	75	<.2	73	---	82	85	227	654	2.2	2.2
			1	67	---	86	88	218	612	3.5	3.8
			10	12	---	--	--	136	237	5.8	7.3
15	45	25	<.2	30	---	69	80	456	583	2.2	2.2
			1	28	32	75	84	435	547	2.5	2.6
			10	5	97	--	--	245	267	4.1	5.1
15	45	75	<.2	24	---	81	89	406	505	2.2	2.2
			1	22	59	86	91	384	475	2.7	2.9
			10	4	98	--	--	233	258	4.5	5.6
15	75	25	<.2	18	---	36	48	501	660	2.2	2.2
			1	17	---	41	52	482	635	2.4	2.6
			10	3	---	--	--	295	390	4.0	5.0
15	75	75	<.2	15	---	61	73	451	594	2.2	2.2
			1	13	---	66	77	432	573	2.6	2.7
			10	2	---	--	--	283	375	4.2	5.3
50	15	25	.2	108	---	40	73	809	911	2.2	2.2
			1	99	---	52	79	764	848	2.8	3.0
			10	18	---	--	--	284	360	3.9	4.7
50	15	75	<.2	86	---	71	85	700	758	2.2	2.2
			1	79	---	80	89	664	706	3.6	3.8
			10	14	---	--	--	259	342	5.6	6.3
50	45	25	<.2	36	---	60	75	621	710	2.2	2.2
			1	33	13	66	79	595	680	2.4	2.5
			10	6	95	--	--	262	361	3.3	3.8
50	45	75	<.2	29	---	76	90	551	629	2.2	2.2
			1	26	39	80	92	528	601	2.7	2.8
			10	5	97	--	--	250	351	3.9	4.5
50	75	25	<.2	22	---	49	64	634	706	2.2	2.2
			1	20	---	55	75	609	673	2.4	2.5
			10	4	---	--	--	364	375	3.2	3.7
50	75	75	<.2	17	---	64	86	567	623	2.2	2.2
			1	16	---	69	88	544	598	2.6	2.6
			10	3	---	--	--	350	356	3.6	4.1

Table A.2 (cont.)

V (cm) VERT	H (cm) HORZ	D (cm) DIST	F (per min)	MAX PERMIS (MPL)	DYNAM % CAP	ISOMETRIC % CAPABLE		BACK COMPRESS.		MET. RATE	
						LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
75	15	25	<.2	120	---	11	17	725	878	2.2	2.2
			1	110	---	20	26	677	827	2.8	2.9
			10	20	---	--	--	256	372	3.6	3.7
75	15	75	<.2	96	---	37	44	611	755	2.2	2.2
			1	88	---	48	55	574	[illegible]	3.8	3.8
			10	16	---	--	--	237	351	5.4	5.5
75	45	25	<.2	40	---	55	68	626	757	2.2	2.2
			1	37	5	62	75	592	722	2.4	2.4
			10	7	94	--	--	260	360	2.8	2.9
75	45	75	<.2	32	---	73	85	538	668	2.2	2.2
			1	29	25	78	90	513	643	2.7	2.8
			10	5	96	--	--	245	345	3.5	3.7
75	75	25	<.2	24	---	47	56	674	726	2.2	2.2
			1	22	---	54	64	641	688	2.3	2.4
			10	4	---	--	--	366	389	2.6	2.8
75	75	75	<.2	19	---	64	74	599	642	2.2	2.2
			1	18	---	69	79	579	619	2.5	2.6
			10	3	---	--	--	352	374	3.2	3.3
125	15	25	<.2	96	---	--	14	589	---	1.9	1.9
			1	90	---	--	20	646	---	2.4	2.4
			10	32	---	--	--	260	---	4.0	4.0
125	15	75	<.2	77	---	--	38	560	---	1.9	1.9
			1	72	---	--	47	527	---	3.2	3.2
			10	26	---	--	--	218	---	6.8	6.8
125	45	25	<.2	32	---	--	74	483	---	1.9	1.9
			1	30	8	--	78	460	---	2.1	2.1
			10	11	79	--	--	208	--	2.7	2.7
125	45	72	<.2	26	---	--	85	401	---	1.9	1.9
			1	24	22	--	88	384	---	2.3	2.3
			10	9	89	--	--	185	---	3.8	3.8
125	75	25	<.2	19	---	--	71	620	---	1.9	1.9
			1	18	---	--	75	600	---	2.0	2.0
			10	6	---	--	--	398	---	2.5	2.5
125	75	75	<.2	15	---	--	81	560	---	1.9	1.9
			1	14	---	--	84	544	---	2.2	2.2
			10	5	---	-	--	375	--	3.2	3.2

Table A.2 (cont.)

V (cm) VERT	H (cm) HORZ	D (cm) DIST	F (per min)	MAX PERMIS (MPL)	DYNAM % CAP	ISOMETRIC % CAPABLE		BACK COMPRESS.		MET. RATE	
						LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
150	15	25	<.2	84	---	--	42	623	--	1.9	1.9
			1	78	---	--	54	584	--	2.4	2.4
			10	28	---	--	--	249	--	3.9	3.9
150	15	50	<.2	71	---	--	68	539	--	1.9	1.9
			1	67	---	--	77	508	--	2.7	2.7
			10	24	---	--	--	218	--	5.1	5.1
150	45	25	<.2	28	---	--	79	437	--	1.9	1.9
			1	26	---	--	84	198	--	2.0	2.0
			10	9	88	--	--	198	--	2.8	2.8
150	45	50	<.2	24	---	--	87	378	--	1.9	1.9
			1	22	34	--	89	361	--	2.2	2.2
			10	8	95	--	--	175	--	3.2	3.2
150	75	25	.2	17	---	--	81	567	--	1.9	1.9
			1	16	---	--	86	543	--	2.0	2.0
			10	6	---	--	--	365	--	2.6	2.6
150	75	50	.2	14	---	--	89	519	--	1.9	1.9
			1	13	---	--	91	503	--	2.1	2.1
			10	5	---	--	--	350	--	2.9	2.9
175	15	25	<.2	72	---	--	13	544	--	1.9	1.9
			1	67	---	--	22	513	--	2.3	2.3
			10	24	---	--	--	223	--	3.7	3.7
175	45	25	.2	24	---	--	95	487	--	1.9	1.9
			1	22	33	--	97	464	--	2.0	2.0
			10	8	---	--	--	286	--	2.8	2.8

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